125

(5) 552800

N-63-4-3

410523

AD No. 410523

DDC FILE COPY

rule

MND-MC-2856

Report Number

(4) $13.00

United States Atomic Energy Commission

Division of Technical Information

OTI-131(May 1962)

USAEC Division of Technical Information Extension, Oak Ridge, Tennessee

(4) $13.00 (5)

This report is prepared under Contract AF 33(616)-6818 for the U.S. Atomic Energy Commission

Special Distribution
MND-MC-2856

MASTER

GENERALIZED MONTE CARLO PROGRAM FOR NEUTRONS--GMCM-9

July 15, 1962

M. Kniedler
T. Jordan

Nuclear Division
Martin Marietta Corporation

(7) NA
(8) NA
(9) NA
(12) NP
(13) NP
(16) NA
(18) NA
(19) NA

(21) supersedes MND-MC-2193.

MND-MC-2856

FOREWORD

This report is submitted by the Nuclear Division of the Martin Marietta Corporation in compliance with Contract AF 33(616)-6818. The report outlines the theory appearing in the GMCM-9 code, and presents the information necessary for use and interpretation of the results of the code. This report supersedes report MND-MC-2193. The code described in MND-MC-2193 was never completely checked out. The code described in this report achieves the goal set forth in MND-MC-2193 by means of a method different than the method used in MND-MC-2193, and has embodied in it features not included in the code described in MND-MC-2193. Appreciation is extended to Mr. Richard Verga of Wright Air Development Division and Mr. Sidney Auslender of Pratt and Whitney Aircraft Corporation for their aid.

ABSTRACT

GMCM-9 is a FORTRAN coded three-dimensional, multiregion, multienergy group, neutronic random walk solution for reactor and shielding problems. Estimates are provided on the neutron flux within various zones of the configuration, the leakage at outer boundaries, and the criticality of reactor configurations. Answers are also obtained on the number of neutrons emerging from elastic scattering, inelastic scattering, and fission for the various materials. The program takes time into account, and may be used to obtain the above answers for successive time periods to investigate the time-dependent nature of a particular reactor configuration.

SUMMARY

The GMCM-9 code for the IBM 7090 is a three-dimensional, multiregion, multienergy group, time-dependent, neutronic random walk solution for reactor and shielding problems. A large enough number of particles* must be followed so that their total behavior is representative of the behavior of the particles in the situation being studied. The nuclear events considered (Chapter V) are particle absorption, fission, and scattering (elastic and inelastic) with provision to add breeding at a later date. The particles are followed from one region to another through the bounding surfaces (Chapter II, Geometry) defining the regions. A particle or its descendant is followed for a period of time specified by an input number; if the particle or its descendant survives time period, it is saved so that it can be used in the next time step.

The initial particles followed are obtained through the generator (Chapter IV) or by using information obtained in a previous run. The generator provides the initial distribution of particles according to the information given it, and stores the necessary coordinates of a number of particles on a tape called the initial value (IV) tape. The particles that reach census time are stored on a census tape. When all particles and their descendants from the IV tape have been followed, the census tape is used to obtain the particles to be followed if the next time step is to be studied.

The answers obtained are from straightforward Monte Carlo calculations and from analytic estimation. Analytic estimation is useful in obtaining answers for those regions where the Monte Carlo sampling is small. The answers obtainable for each census period are:

(1) The number of particles leaking from the system.

(2) The number of neutrons leaking from the system.

(3) The number of neutrons entering the special tally regions (Chapter II) versus energy.

(4) System criticality.

(5) Number of neutrons scattered elastically.

(6) Number of neutrons scattered inelastically.

*See Chapter III for definition of a particle.

(7) Number of fission neutrons born versus energy.

(8) Number of neutrons absorbed.

(9) Number of particles and neutrons starting their life history for the census period.

(10) Number of particles and neutrons that remain in the system after the census period.

(11) Neutron flux versus region and energy group.

(12) Number of neutrons crossing from region ℓ to region ℓ' (maximum of 10 ℓ; ℓ' pairs).

(13) Number of neutrons scattered elastically versus material and energy group.

(14) Number of neutrons scattered inelastically versus material and energy group.

(15) Number of neutrons born in fission versus material and energy group.

(16) Number of times the collision routine was entered versus material and energy group.

(17) Total number of times the collision routine was entered.

(18) Total number of particles on census tape.

(19) The number of neutrons and particles that falls below the energy cutoff.

(20) The last random number used in the calculation.

It is impossible to give the running time for a sample problem that will allow extrapolation to predict running times for a different type of problem. This situation exists because the running time of Monte Carlo is highly dependent on the geometry of the system being studied, the reactivity of the system, and the magnitudes of the elastic and inelastic scattering and absorption cross sections for the materials present in the system.

GMCM-9 is coded in FORTRAN for operation on a 32 K IBM 7090, and can be run at any installation that uses the SHARE mode of operation. The code requires a maximum of 10 magnetic tapes, but may operate with as few as six magnetic tapes (see the note on Card Type 2 in Chapter IV). The input, output and chain tapes are those assigned by the installation. The code is instructed through the input which tapes to use as input, output and chain tapes. No magnetic drums are used.

In addition to the above-mentioned facts, GMCM-9 embodies the following features:

(1) Inelastic scattering matrix is included in the collision routine (Chapter V).

(2) A scheme (Russian Roulette) to ensure that the weight of the particle being followed is large enough to make significant contributions to the results (Appendix I).

(3) GMCM-9 is a time study problem in that it follows the particles and their descendants for a specified time called the census time (Chapter II) to obtain the Monte Carlo and analytic estimation results. The problem can be run for more than one time step using as sources the particles that had reached census time on a previous run (Chapter VI). The length of a census period is an input number. During each run, the particles that reach census time are written on a tape referred to as the census tape; it is the information on the census tape that describes the source for the next run.

(4) Splitting of the particles into prescribed number of particles with a corresponding reduction of weight for each of the split particles takes place in certain predetermined regions when a collision occurs in these regions. The purpose here is to increase the reliability of the results by increasing the number of particles followed in regions far removed from the source. The number of particles into which the original particle splits as well as the regions where this process is to occur is entered as input (Chapter VI).

(5) The geometrical configurations that can be studied are very general. The surfaces bounding a region are defined in the Cartesian coordinate system (x, y and z) by generalized quadratic equations (Chapter II, 5).

(6) The distance a particle travels before suffering a collision is found by picking from an exponential distribution; the procedure for picking out of this distribution is outlined in Appendix C.

(7) The neutron collision routine uses random sampling from the appropriate discrete distributions to select either an elastic scatter event, an inelastic scattering event, a fission event, or an absorption event.

(8) For a fission event the weight of the incident neutron is considered in determining the actual number of particles to follow. The angular distribution of the fission-produced particles is assumed isotropic in the laboratory system.

(9) The emission of gamma rays due to inelastic scattering is allowed and the appropriate coordinates for the gammas are stored on magnetic tape.

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

I. INTRODUCTION

GMCM-9 is a three-dimensional, multiregion, multienergy, time-dependent neutronic random walk solution for reactor and shielding problems.

GMCM-9 has been coded in FORTRAN for the IBM 7090 for the Wright Air Development Division by the Martin Marietta Corporation.

II. GENERAL INFORMATION

A. PROBABILITY THEORY

The method of calculation relies on the following fact. If sufficient neutronic random walks are formulated during the calculation in a way consistent with the nuclear and geometrical properties of the configuration, then the population of neutron path lengths, leakages, and collisions determined in the calculation will be a statistical approximation of the population that would occur in a real system of the same configuration. Thus, the calculation is primarily concerned with creating neutronic random walks which are as consistent as is practical with the physical model that is to be investigated.

Much of the physical information can be treated according to the laws of probability. For example, neutrons born in fission must be assigned energies which reflect the available information on the fission neutron energy spectrum. This energy spectrum is interpreted as a probability density function that provides the necessary information on the relative frequencies at which fission neutrons appear in the various portions of the energy scale. The code then uses a method (into which the information in the probability density function is incorporated) which assigns energies to neutrons born in fission in such a way that the probability that an assigned energy will be in a particular portion of the energy scale is proportional to the relative frequency of birth of fission neutrons in that portion of the energy scale. By this method particular values can be chosen for the variables which describe the neutronic random walk, and each phase of the random walk can be consistent with the available knowledge on neutron diffusion through material bodies.

B. TYPICAL PROBLEMS SOLVED BY GMCM-9

GMCM-9 can provide information on the neutron flux within the neutron leakage from a geometrical configuration which may simulate either a reactor, shield, or both. An example of a practical configuration which can be simulated by GMCM-9 is the Oak Ridge National Laboratory (ORNL) Lid Tank and any ordinary arrangement of shielding materials in it. Fission neutrons with approximately the correct distribution in both space and energy can be started from within the mockup source plate, and their neutronic random walks can be followed through the mockup lid tank configuration. Flux information is then available for each of the various energy groups in each of the regions of the configuration. Information on the source of inelastic gamma rays is available. Further fissions in the source plate, due to neutrons born in the source plate, are automatically calculated by the code.

Another configuration that can be simulated is a reactor with parallel fuel plates. The original population of neutrons is specified to start from the fuel plates, and succeeding generations of neutrons are born in a source density which is more and more characteristic of that configuration. The time required for the source to settle down to the equilibrium distribution is equivalent to the time required for a real reactor of this configuration to settle down to an equilibrium spatial distribution of the source (if the initial conditions for that source are the same as for the calculation). The criticality of the system, as well as the flux and leakage, can be estimated by this calculation. The calculation is limited for this application in that the effect of delayed neutrons is not included, although it could be. However, for an equilibrium flux the knowledge of the source that effected it and the fission ratio consistent with that flux provides an estimate of the criticality of the system.

C. CENSUS TIME

Census time is the real lifetime for which a neutron or its descendents is followed by the code. Census time is entered as an input number (Chapter VI).

Upon reaching census time the particle coordinates are written on a census tape for further processing.

D. DELW

DELW is the fraction of the original weight* W of each particle that is used as the criterion for either continuing to follow the particle or playing Russian Roulette (Appendix I). In the game of Russian Roulette, the particle is either killed (life history is terminated) or its weight is increased and its life history is continued to be followed.

The weight (W) of the particles being traced by the code is compared to DELW at appropriate points in its life history to ensure that its contribution to the results will be significant. More detailed information can be found in the flow diagrams.

*The original weight of the particle is the weight of the particle at the beginning of its life history.

E. GEOMETRY

1. Surfaces-Unique

In describing the system of interest, the system is divided into a number of regions sufficient to describe the actual system. Each of the regions used in mocking up the system is bounded by one or more surfaces. Each surface bounding a region must also be the boundary of at least one of the neighboring regions. Therefore, to eliminate duplication of input, the unique surfaces bounding all regions are input separate from the regions. In describing the boundaries of a region it is then necessary to specify the number of the surface as determined by its position in the input.

The general equation for a surface is

$$Ax^2 + X_o x + By^2 + Y_o y + Cz^2 + Z_o z = K \qquad (2.5.1)$$

where A, B, C, K, X_o, Y_o, and Z_o are constants and x, y, and z are the Cartesian coordinates of the surface. To permit more rapid calculation, six special forms of the equation are used. Introduction of these special forms necessitates the use of another constant, NT, which designates the form of the equation to be used. For the general equation, NT = 1. The six special forms of the equation and the corresponding value of NT are:

NT	Equation	
2	$0 = A(x - X_o)^2 + B(y - Y_o)^2 + C(z - Z_o)^2 - K$	(2.5.2)
3	$0 = (x - X_o)^2 + (y - Y_o)^2 - K$	(2.5.3)
4	$0 = x - K$	(2.5.4)
5	$0 = y - K$	(2.5.5)
6	$0 = z - K$	(2.5.6)
7	$0 = X_o x + Y_o y + Z_o z - K$	(2.5.7)

Input for each surface consists of the eight constants NT, A, B, C, K, X_o, Y_o, and Z_o (Card Types 14 and 15) even though, for some forms of the equation, they are not all used, i.e., NT = 4, A, B, C, Y_o, Z_o are all 0.0 and X_o = 1.0; any number could be input for any of

these constants since the equations used by the code do not require their use.

Surfaces that can be represented by the general equation and its six special forms range from any generalized quadratic surface to a plane. However, for speed in computation it is best to represent a surface using the simplest possible form of the equation.

2. Region

A region is a volume of the system being studied. Each region is identified by the value of the index NR assigned to each region, based on the order of input. The material assigned to each region is treated as a homogeneous mixture and is assigned by the number MN (Card Type 16), the location of the material in the list of materials.

3. Inside-Outside Regions

If a region is one in which a particle's history is of interest, the region is an inside region. An outside region is one for which a particle's history is no longer of interest. Particles entering outside regions are said to have leaked from the system. For an inside region, the input number (Card Type 16), NOR is 0 and for an outside region, NOR = 1.

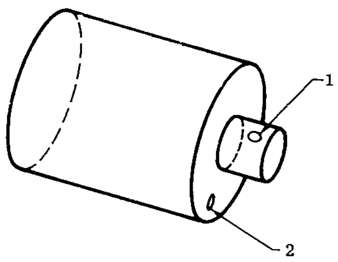
The input number NPFC (Card Type 16) is the number of particles to be followed from an elastic or inelastic scattering in this region. NPFC must be an integer. An input of 0 for this number is equivalent to an absorption when following the scattered particle. If the interaction of a particle in this region is a fission, NPFC is multiplied by the number of particles per fission (determined by NFISF) to give the total number of particles followed from the fission event. In all cases, the weight of particles after the interaction are adjusted to conserve neutrons.

4. Surfaces as Related to Regions

A region can be bounded by a maximum of six surfaces. The number of surfaces bounding a region is an input number, NSMAX (Card Type 7).

5. Ambiguous Boundaries

Using the concept of ambiguous boundaries can simplify input to the problem and increase the generality of possible region shapes. An ambiguous boundary is a true boundary of part of the region. In general, if a region has one ambiguous boundary it has at least two. Input for a region is limited to the cases of no ambiguous boundaries or two ambiguous boundaries (see Fig. 1). Consider the total volume enclosed



1. This surface is a true boundary for the smaller cylinder but is ambiguous for the region represented by the two cylinders
2. This surface is a true boundary for the larger cylinder but is ambiguous for the region represented by the two cylinders

Fig. 1. Example of Ambiguous Boundaries

by both cylinders in Fig. 1. Surface (1) is a true boundary for the smaller cylinder but is ambiguous for the region represented by the two cylinders. Surface (2) is a true boundary for the larger cylinder but is ambiguous for the region represented by the two cylinders. With the concept of ambiguous boundaries, a region represented by the two cylinders can be inputed as one region. It can also be inputed as two regions if desired.

If a region has ambiguous boundaries, the input number NAB = 1 (Card Type 16). If there are no ambiguous boundaries, NAB = 0.

In describing the surfaces bordering a region, ambiguous boundaries-if any-must be described first. For all other surfaces, the sequence of description is of little importance.

6. Ambiguity Index for Surfaces

For each surface bordering the region specified by NOS (Card Type 17), the location of the surface in the list of unique surfaces, there is the input number AI (Card Type 17) the ambiguity index of the surface. This number is + 1.0 if the function $r = (Ax^2 + X_o x + By^2$ $Y_o y + Cz^2 + Z_o z - K)$ changes from negative to positive as a particle leaves the region through the surface. (x, y, z are the coordinates of the particle and A, B, C, X_o, Y_o, Z_o, K are the surface constants.) In this case the surface is called an outside surface of the region. Similarly, AI = - 1.0 if r changes from positive to negative as a neutron crosses the surface in leaving the region. In this instance the surface is said to be an inside surface of the region.

7. Calculation of Distance to Boundary

The equations for the surfaces are used for determining the distance between a point in a region and each of its boundaries along a line in the direction that a particle is traveling.

Let

x, y, z	= coordinates of the point
α, β, γ	= direction cosines of the velocity vector
x', y', z'	= coordinates of the point on the boundary where the intersection occurs
S	= distance between the two points.

Then

$$x' = x + \alpha S \qquad (2.5.8)$$

$$y' = y + \beta S \qquad (2.5.9)$$

$$z' = z + \gamma S \qquad (2.5.10)$$

Substituting in the general equation of the surface

$$A(x + \alpha S)^2 + X_o(x + \alpha S) + B(y + \beta S)^2 + Y_o(y + \beta S) + C(z + \gamma S)^2$$
$$+ Z_o(z + \gamma S) - K = 0$$

requires the form

$$hS^2 + 2eS + r = 0$$

Then

$$h = A\alpha^2 + B\beta^2 + C\gamma^2 \qquad (2.5.11)$$

$$e = \alpha(Ax + X_o) + \beta(By + Y_o) + \gamma(Cz + Z_o) \qquad (2.5.12)$$

$$r = x(Ax + X_o) + y(By + Y_o) + z(Cz + Z_o) - K \qquad (2.5.13)$$

with similar equations for the other forms of the general equation.

The distance, S, to the surface is calculated as

$$S = \frac{1}{h}\left[-e \pm \sqrt{e^2 - hr}\right] \qquad (2.5.14)$$

The smallest, finite, positive root is accepted as the distance to the boundary. If there is no such root, no intersection exists. An attempt is made to calculate an S for each boundary assigned to the region. The smallest of the acceptable S's is designated SP, and the boundary, NS, for which this S was calculated is chosen as the one that would be crossed if the particle travels that far before collision or census time. The calculation is accepted as correct unless the region has ambiguous boundaries and the smallest distance corresponds to one of these boundaries. In this case the coordinates of the particle are stepped over the boundary and a test made to see if the particle is actually outside the region. If so, the calculated SP is then accepted as correct. If it is found that the particle would still be inside the region, SP is rejected and the next smallest of the S's is chosen as SP and is accepted as correct unless it corresponds to the other ambiguous boundary, in which case the same test is made again. More detailed information on the calculation of distances can be found in Subroutine SFIND.

8. Next Region

The equations of the surfaces are also used to determine the next region entered by a particle if it does cross a boundary. For each boundary of a region, the four most probable next regions a particle would enter on crossing that boundary are specified by input as MP(J), J = 1, 2, 3, 4 (Card Type 17).

On testing a region for acceptance as the next region entered by a particle the following test is made. First $r = (Ax^2 + X_o x + By^2 + Y_o y + Cz^2 + Z_o z - K)$ times AI is calculated for each surface of the region. If all are negative the region is accepted. If one is positive and corresponds to an ambiguous surface of the region, the region is accepted. In all other cases the region is rejected.

In locating the next region entered by the particle, region number MP(1) is tested first. If it is accepted the search stops. If not accepted, regions MP(2), MP(3), and MP(4) are tested next. If no region is accepted the search continues with region MP(4) + 1 to region NRMAX and from there to region 1 through region MP(4) - 1. If at any time a region is accepted as the correct region the search stops.

The four regions specified as most probable next regions do not have to be correct. They must however, be in the list of regions, that is, $1 < MP(J) < NRMAX$. A more detailed description of the location of the region a particle resides in can be found in Subroutine RFIND.

9. Error in Calculations

If there is faulty region or surface input and it is impossible to find an SP or the next region, a tally, NREJCT, is increased by 1 and a new particle is followed. When this tally reaches 5, tracing of particles is discontinued and such tallies as have been made are written on the output tape and the calculation terminated.

10. Rules for Mockup

The following rules must be followed in formulating the input for the geometry of a problem:

(1) No two regions may overlap (have any common volume).

(2) The space occupied by the system must be occupied by either inside regions or outside regions.

(3) The outermost regions of the system must be outside regions (allows the possibility of an isolated outside region(s) surrounded on all sides by inside regions).

(4) All regions must be assigned at least one boundary.

(5) Ambiguous boundaries, if any, must be assigned first.

It is evident from the sequence of events in both the search for a region and the calculation of a distance to boundary--two portions of the code in which a great portion of the calculation time is spent--that the choice of boundaries and regions and the manner in which they are sequenced in that portion of the input that describes the regions for a particular problem can greatly affect the running time needed for that problem. In some problems the choice between a good and a poor way of describing the geometry can easily alter the running time by a factor of two. The poor method for describing the geometry will give results identical to those which could be achieved with the faster calculation.

F. SPLITTING

Splitting results in a change in the number of particles being followed, and occurs at points of collision. The number of particles into which a particle splits in each region is entered as an input number (NPFC on Card Type 16, Chapter VI). The particles' weights must be adjusted to eliminate the bias introduced by this scheme. This is accomplished by requiring that the total number of neutrons involved before and after the collision be conserved:

Weight of each particle after scattering = W'

Weight of particle before scattering = W

Number of particles after split = NPFC

$$W' = \frac{W}{NPFC}$$

If the collision process is a fission, the code follows either 3 or JMAG particles after a collision (if NPFC = 1) depending on the input number NFISF described on Card Type 8 in Chapter VI. In either case the weight W' must be adjusted according to the following formula

$$W' = \frac{W * \nu}{NPFC * 3} \quad \text{if 3*NPFC particles are followed or}$$

$$W' = \frac{W * \nu}{NPFC * JMAG} \quad \text{if NPFC * JMAG particles are followed,}$$

where ν is the number of particles per fission.

G. GAMMAS DUE TO INELASTIC SCATTERING

If it is desired, the coordinates of the gammas born of inelastic scattering can be saved on a magnetic tape to be processed at a later time. The coordinates that are written in binary in blocks of 30 each time an inelastic scattering event occurs are:

x, y, z; the Cartesian coordinates of the scattering point

MRG; the region in which the scattering occurred

EGAM; the energy of the gamma

W; the weight of the neutron that was scattered.

The control word (NGAM) which instructs the code to calculate or delete the calculation of and writing of the gamma coordinates due to inelastic scattering on a tape is entered on Card Type 8. Further details can be found in the flow diagrams.

H. BREEDING

Breeding is considered in the present code only to the extent that the weight of the particle causing breeding and the region index in which the event takes place is saved on a tape for future processing. If breeding is to be considered in the calculation, the isotope which will cause breeding must be the first isotope in the description of the material. In order to keep track of the neutron economy, a breeding event is tallied as an absorption by the code. A separate tally is made of the number of neutrons which suffer a breeding event. The input number (NBREED) which instructs the code that the first isotope of the material is a breeder is entered on Card Type 18. Further details can be found in the COLISN flow diagram (see Fig. D-3).

I. SPECIAL TALLY REGIONS

Any three regions of the system studied may be designated as special tally regions. The total number of neutrons entering each of these regions will be tallied for each census time. The three special tally regions (NSTR) are inputed on Card Type 10.

J. MIGRATION TALLIES FROM REGION ℓ TO REGION ℓ'

It is possible to designate up to 10 pairs of regions (ℓ, ℓ') for which a tally is made of the neutrons crossing from region ℓ to region ℓ'.

The number of region pairs for which this type of tally is made is inputed on Card Type 8. The region pairs for which the tallies are to be made are inputed on Card Type 11.

III. PROGRAM SEQUENCE OF OPERATIONS

An attempt is made here to give a brief word description of the operation of GMCM-9. It is hoped that this overall picture of the flow of information in the code will aid in understanding the code. For details beyond this brief word picture, reference must be made to the flow diagrams.

In a true physical situation, neutrons are identified as whole neutrons; statistically speaking, the neutrons are said to have a weight of one. In this program a neutron may have a weight different from one in which case the neutron of weight (W) is referred to as a particle.

The program is divided into three distinct parts (Chains 1, 2 and 3), each chain depending on the one which precedes it. In general, the first chain reads the input, writes the input on the output tape, calculates the storage requirements, generates the coordinates of the particles to be followed (unless they are on tape) and calculates the total macroscopic cross section for each material along with the cumulative probabilities of interaction (breeding, absorption, fission, elastic scattering and inelastic scattering) for each energy group and isotope in each material. The second chain follows the life histories of the particles and tallies the answers. The third chain performs additional calculations on the tallies to express some of them in more meaningful form, and writes the answers on output tape. With this general picture in mind, the remainder of this chapter will be devoted to a more detailed explanation of Chains 1 and 2.

A. CHAIN 1

The object program and the input is read from cards onto the input tape. The P-PREP routine of Chain 1 writes the input, variable by variable, on the output tape as the variables are read in from the input tape. This scheme provides a check on data which may be incorrect in the sense of being out of order or in the incorrect mode (see input). The storage requirements are then calculated. If the storage requirements exceed 18,000, the code indicates that the storage requirements have been exceeded and stops. The problem can be resubmitted after it has been rearranged to reduce some of the storage required. The means of accomplishing this is discussed in Chapter VI under Trading Storage.

The next calculation performed in Chain 1 is that for the total macroscopic cross section for each material and energy group along with the cumulative probabilities of breeding, absorption, fission, and

scattering, elastically and inelastically, for each isotope and energy group in each material.

The coordinates for the number of particles (position, direction, velocity, region, energy group, weight and time) requested in the input is then generated by picking from the appropriate cumulative probability distribution tables. The coordinates are written on the IV tape in records of 10 particles. The code then enters Chain 2 for its next operation. If the coordinates of the particle are on tape (labeled the census tape)* the particle coordinate generator portion of P-PREP is bypassed and Chain 2 is entered.

B. CHAIN 2

The main program of Chain 2 performs the calculation of the histories of the particles. The answers are tallied by straight Monte Carlo methods and/or analytic estimation (Appendix G). Chain 2 begins by selecting the coordinates of a single source particle from memory. If no coordinates are available in memory, then a record of coordinates of particles is loaded into memory from the magnetic tape generated in Chain 1 or from the census tape (CT). If there are no more records of particles on tape, then Chain 3 is entered. If the particle coordinates are taken from the IV tape, the number of mean free paths to the next collision is picked from a random exponential distribution (EXPP). If the particle chosen is from the CT, the number of mean free paths to collision is included with the particle coordinates. In either case the appropriate contributors are made to the particle and neutron tallies of the number of particles and neutrons followed.

If analytic estimation is not requested, the distance the particle must travel in order to escape the region is determined in subroutine SFIND. SFIND determines this distance by calculating the distances to each surface bounding the region from the spatial coordinates and direction cosines of the particle. The smallest of these distances (provided the path length to the surface lies in the region) is the distance the particle must travel in order to escape from the region. The material for the region is found and the time the particle will be in the region until the particle escapes from the region is added to the time the particle has been in the system. If this time exceeds the census time, the distances the particle must travel with velocity VEL in order to reach census time is determined. If at any point during the history of the particle the cross section for the region is zero, appropriate forks are set in the code to eliminate unnecessary calculations. The particle is checked to determine if a collision has occurred for the particle with its present set of direction cosines. The number of mean free paths the particle will have traveled from the Cartesian coordinates of the particle as it came from tape or the last point of collision to the point where it will escape the region it is in or exceed census time (SPMFP) is then compared with EXPP, the number chosen from the exponential distribution. If SPMFP is larger than EXPP, the flux is tallied and the collision routine (COLSN) is entered. The collision routine is described in some detail in the appendix and in the flow diagrams; the routine essentially determines the type of interaction the neutron will experience, assigns new direction cosines and velocity to the particle or makes provisions for these to be calculated at another point in the calculation, depending on the type of interaction, and makes appropriate tallies. The code then searches for a new particle to follow. If no collision is to occur (SPMFP < EXPP), the flux is tallied for the material and energy group and the time is checked against the census time. If the census time has been exceeded, the appropriate particle coordinates are written on the census tape and the code searches for another particle to follow. If the census time is not exceeded, the region the particle will enter next is determined by subroutine RFIND and the process is repeated by starting with the calculation of the distance required to escape from the new region.

If analytic estimation answers are requested the particle history is followed exactly as in the case described above (no analytic estimation answers requested), with the exception that certain tallies are made by using the analytic estimation results instead of the straightforward Monte Carlo results (see Chapter VII) and the code continues to follow the particle even after a collision has occurred until the particle escapes from the system, exceeds census time, or falls below the weight cutoff so that analytic estimation answers may be tabulated. If a collision has occurred before a particle has exceeded census time (analytic estimation answers requested) the particle coordinates are not written on the census tape. After the code is finished following a particle, a new particle is chosen to follow.

*The census tape contains the coordinates of the particles that have exceeded the census time on a previous run. The coordinates saved are position, direction, velocity, energy group, region, weight, weight cutoff and the number of mean free paths to the next collision.

IV. PARTICLE COORDINATE GENERATOR OF CHAIN 1

The generator portion of the first chain prepares the initial value tape. The input number, NKASE (Card Type 29), represents the number of times the generator calculation will be repeated to obtain a more detailed representation of the source. If NKASE is zero, the generator is bypassed. In this case a previously prepared initial value tape, which fits the structure of the problem, must be used. This does not mean a census tape from a previous problem, since the census tape includes several additional coordinates.

The initial value tape contains all quantities needed to describe the source particles. These are the Cartesian coordinates, direction cosines, velocity, energy group, weight, region, and time of birth. These generalized coordinates are written in records of 10 particles each on the initial value tape.

The Cartesian coordinates (x, y, and z), direction cosines (α, β, and γ), velocity, and energy group are generated from several input table pairs (Card Types 35 and 36); L-L', M-M', N-N', O-O', P-P', R-R', and S-S' corresponding to J = 1, 2, ..., 7. The unprimed table of a given pair is a set of integrated probabilities of which the first is 1.0 and the last 0.0. The primed table of this pair is a set of coordinates from which a particle coordinate will be chosen. For example, the L, L' tables are used to select the value of a coordinate, the z coordinate; L consists of a set of L_i, and L' consists of a set of L_i'. L_i is the probability that $z \leq L_i'$ (see Appendix D). The number of entries in each table of a given pair, corresponding to J, is IMX(J) an input quantity (Card Types 32 and 33). The tables used depend on the input numbers NA and NE (Card Type 30).

NA determines the tables and method used in generating the Cartesian coordinates of the particles. These are:

NA = 1 Z, X, Y are generated using the table pairs L-L', M-M', and N-N', respectively. Special cases are:

(A) Plane source:

(1) Parallel to XY plane:

(a) Use two entries in L-L' tables

(b) Set $L_1 = 1.0$, $L_2 = 0.0$

(c) Set $L_1' = Z_o$, $L_2' = Z_o$

(2) Similarly for planes parallel to XZ and YZ planes.

(B) Line source:

(1) Parallel to X-axis:

(a) Use two entries in L-L' and N-N' tables.

(b) Set L_1 and $N_1 = 1.0$, L_2 and $N_2 = 0.0$.

(c) Set $L_1' = Z_o$, $L_2' = Z_o$; $N_1' = Y_o$, $N_2' = Y_o$.

(2) Similarly for lines parallel to Y and Z axis.

(C) Point source:

(1) Use 2 entries in L-L', M-M', and N-N' tables.

(2) Set L_1, M_1, $N_1 = 1.0$; L_2, M_2, $N_2 = 0.0$.

(3) Set L_1', $L_2' = Z_o$; M_1', $M_2 = X_o$; N_1', $N_2' = Y_o$.

NA = 2 Z is generated using the L-L' tables. $\rho = \sqrt{x^2 + y^2}$ is chosen from the 0-0' tables. $|x|$ is selected at random from a uniform distribution between 0.0 and ρ. $|y|$ is calculated as $|y| = \sqrt{\rho^2 - x^2}$. The signs of x and y are chosen at random.

(D) Special cases:

(1) Plane source parallel to XY plane.

(2) Line source along Z axis.

(3) Point source at (0, 0, Z_o).

NA = 3, 4 Z is generated using the L-L' tables. $\rho = \sqrt{x^2 + y^2}$ is chosen from the 0-0' tables. $|x|$ and $|y|$ are calculated subject to the restriction $0_i \le \sqrt{x^2 + y^2} \le 0_{i-1}$ where the $0_i'$'s are entries in the 0' table and the values of $|x|$ and $|y|$ used are $|x| = \xi_1 0'_{i-1}$ and $|y| = \xi_2 0'_{i-1}$ where ξ_1, ξ_2 are random numbers between

0 and 1.0. After meeting this restriction the signs of x and y are chosen at random.

(E) Special case:

Plane source parallel to XY plane

NA = 5 $r = \sqrt{x^2 + y^2 + z^2}$ is chosen from the L-L' table $|x|$, $|y|$, and $|z|$ are chosen with the restriction $L_i' \le \sqrt{x^2 + y^2 + z^2} \le L'_{i-1}$ where the L_i''s are entries in the L' table. The values used for $|x|$, $|y|$, and $|z|$ are: $|x| = \xi_1 L'_{i-1}$; $|y| = \xi_2 L'_{i-1}$, and $|z| = \xi_3 L'_{i-1}$. After locating suitable values for ξ_1, ξ_2 and ξ_3 the signs of x, y, and z are chosen at random.

Also used in the generation of the Cartesian coordinates are the input numbers NTRA (Card Type 30), XZRO, YZRO, and ZZRO (Card Type 31). If NTRA = 0, the X, Y, and Z coordinates are written on the initial value tape as calculated. If NTRA = 1, the coordinates are translated by XZRO, YZRO, and ZZRO before being written on tape. This allows the generation of a spherical or cylindrical source other than at the origin.

NE (Card Type 30) determines the method of calculating the direction cosines. These are:

NE = 1 α, β, γ are chosen isotropically using no tables.

NE = 2 γ is chosen from the R' table ($-1 \le \ \le 1$), α and β are chosen uniformly over their intervals subject to the condition that $\alpha^2 + \beta^2 = 1 - \gamma^2$ Special Case $\gamma = \gamma_o$.

NE = 3 γ is selected from the R' table ($-1 \le \ \le 1$). α is selected from the S' table ($-1 \le \ \le 1$) and β is calculated as $\beta = \sqrt{1 - \alpha^2 - \gamma^2}$ Special Case $\gamma = \gamma_o$, $\alpha = \alpha_o$, $\beta = \sqrt{1 - \alpha_o^2 - \gamma_o^2}$.

The velocity group and the energy group are generated using the P-P' table. ξ ($0 < \xi < 1$) is located in the P table ($P_i \le \xi \le P_{i-1}$). The energy group is i-1, and the velocity is chosen from a uniform

distribution between P_{i-1}' and P_i'. For a monoenergetic source of energy E_o corresponding to the energy group J_o, input the P-P' tables with $J_o + 1$ entries each with $P_i = 1.0$ for $i = 1, 2, \ldots, J_o$ and $P_{J_o+1} = 0.0$ and input all $P_i' = E_o$.

The weight of each particle generated is WIN and input number (Card Type 31). The time of birth of the particle is dependent on NH, an input number (Card Type 30). If NH = 0 the time of birth is set at 0.0. If NH = 1, the time of birth is selected from a uniform distribution between 0.0 and TIN, an input time (Card Type 31).

The region of birth of each particle is also input as NRIN (Card Type 30). The coordinates generated must correspond to this region for the problem to run.

It is possible to generate particles using more than one set of input table pairs L-L', M-M', N-N', O-O', P-P', R-R'. In this case NKASE represents the number of input table pairs. The total number of particles generated for each case is determined by NPIV, an input number (Card Type 30). NPIV is the total number of particles generated up to and including a given set of generator input.

The coordinates of the first 50 particles generated and written on the initial value tape are also written on the printout.

V. CROSS-SECTION PORTION OF CHAIN 1

The nuclear data needed by the code is supplied by card input. For several problems having identical material and isotope input, the cross-section tape generated by the first problem can be used to input the majority of the nuclear data for successive problems.

The input can be divided into two sections: the first section describes materials, and the second section describes isotopes. The material input consists of:

MMAX	=	total number of materials
NIMAX(M)	=	number of isotopes of the Mth material
NBREED(M)	=	breeding option for the Mth material
RHO(M)	=	density (g/cm^3) of the Mth material
K(NI,M)	=	identification of the NIth isotope of the Mth material (location of the isotope in the input for isotopes)
WTF(NI,M)	=	weight fraction of the NIth isotope of the Mth material.

The isotope (used interchangeably with element) input used in calculating cross sections and interaction probabilities consists of:

NFI	=	total number of fissionable isotopes
IMAX	=	total number of isotopes (including fissionable isotopes)
A(I)	=	atomic mass (amu) of the Ith isotope
SEL(J,I)	=	microscopic elastic scattering cross section
SIN(J,I)	=	microscopic inelastic scattering cross section
SFIS(J,I)	=	microscopic fission cross section
SCAP(J,I)	=	microscopic capture cross section,

where J is the energy group. The microscopic cross sections all have units of barns.

Also input for each fissionable isotope are:

FS(J,I) = probability of a particle being born at the energy level J or below (fission spectrum)

PNU(J,I) = neutrons born per fission for an incident neutron in energy group J.

The input for fissionable isotopes must precede that of the other isotopes. Also, when assigning isotopes to materials, if the material is to have breeding, the breeding isotope must be the first isotope assigned. Fissionable isotopes must also be assigned to a material before other isotopes. If a material has fissionable isotopes it can have breeding only if the first fissionable isotope and the breeder isotope are identical.

This input is used to calculate the following quantities used in tracing particles:

XSECT(J,M) = total cross section (cm^{-1}) for material M, energy group J

PSE(NI,J,M) = probability of an elastic scatter off the NIth isotope of material M for a particle in energy group J

PSI(NI,J,M) = probability of an inelastic scatter off the NIth isotope of material M for a particle in energy group J

PSF(NI,J,M) = probability of a fission with the NIth isotope of material M for a particle in energy group J

PS(L,J,M) = L = 1, neutrons from elastic scattering

L = 2, neutrons from inelastic scattering

L = 3, neutrons from fission scattering

for an interaction with material M by a neutron in the Jth energy group

PB(J,M) = probability of breeding (capture by the first isotope of material M for a particle in the Jth energy group interacting with the Mth material

These quantities are calculated for material M using the following intermediate quantities:

$$\text{SUM 1 (NI, J)} = \sum_{N=1}^{NI} \text{SEL(J, I)*WTF(N, M)/A(I); where I =}$$

K(N, M) and WTF(N, M) is the weight fraction of isotope N in material M.

$$\text{SUM 2(NI, J)} = \sum_{N=1}^{NI} \text{SIN(J, I)*WTF(N, M)/A(I); I = K(N, M)} \quad 5.2$$

$$\text{SUM 3(NI, J)} = \sum_{N=1}^{NI} \text{SFIS(J, I)*WTF(N, M)/A(I); I = K(N, M)} \quad 5.3$$

$$\text{SUM 4(J)} = \sum_{N=1}^{NIMAX(M)} \text{[SEL(J, I) + SIN(J, I) + SFIS(J, I)} \quad 5.4$$

$$\text{+ SCAP(J, I)] *WTF(N, M)/A(I), where}$$

I = K(N, M) is the index used in identifying the isotope's atomic mass and cross sections.

Using these quantities, the calculation proceeds as follows:

XSECT(J, M)	= 0.6023*RHO(M)* SUM 4(J)	5.5
PSE(NI, J, M)	= SUM 1 (NI, J)/SUM 4(J)	5.6
PS(1, J, M)	= PSE(NIMAX(M), J, M)	5.7
PSI(NI, J, M)	= PS(1, J, M) + SUM 2(NI, J)/SUM 4(J)	5.8
PS(2, J, M)	= PSI(NIMAX(M), J, M) - PS(1, J, M)	5.9
PSF(NI, J, M)	= PSI(NIMAX(M), J, M) + $\frac{\text{SUM 3(NI, J)}}{\text{SUM 4(J)}}$	5.10
If NBREED(M)	= 1	
PB(J, M)	= PSF(NIMAX(M), J, M) + $\frac{\text{SCAP(J, I)*WTF(1, M)}}{\text{A(I)*SUM 4(J)}}$	5.11

where I = K(1,M)

$$PS(3,J,M) = \frac{\left[\sum_{N=1}^{NMAX} SFIS(J,I)*WTF(N,M)*PNU(J,I)/A(I)\right]}{SUM\ 4(J)} \quad 5.12$$

where I = K(N,M) and NMAX is the total number of fissionable isotopes in material M.

This method of calculation gives probabilities for interaction of the following type.

In choosing the interaction and isotope for a particle in the Jth energy group having a collision in the Mth material, the probabilities in ascending order are:

PSE(1,J,M)

(2,J,M)

.
.
.

(NI,J,M)

.
.
.

(NIMAX(M),J,M) = PS(1, J, M)

PSI(1,J,M)

(2,J,M)

.
.
.

(NI,J,M)

.
.
.

These cumulative probabilities are monotonically increasing, the first being $\geq 0.$ and the last being ≤ 1.0

(NIMAX(M),J,M) = PS(1, J, M) + PS(2, J, M)

PSF(1,J,M)

(2,J,M)

.
.
.

(NI,J,M)

.
.
.

(NIMAX(M),J,M)

and, if NBREED(M) = 1

PB(J,M)

The probabilities, PS(L,J,M) are used in the analytic estimation routine for making tallies of neutrons from elastic and inelastic scattering and fission.

Input for each isotope also includes the inelastic scattering matrix (Card Type 22). If all inelastic scattering cross sections are zero it will not be used, but must still be inputed. This matrix, consisting of the elements P(J',J,I) is a triangular matrix, since inelastic scattering is only to energies below the incident particle energy. P(J',J,I) is the probability of a particle scattering inelastically from isotope I, originally in energy group J, and ending up in energy J'. The inelastic scattering matrix is tabulated for the center of mass coordinates.

VI. INPUT

A. SEQUENCE OF GMCM-9 DECK

The sequence of GMCM-9 Deck is shown in Fig. 2.

B. INPUT FORMAT

The input is entered into the machine in one of the three formats which are described below.

FORMAT 1. Fixed point (I12). The decimal point is not punched and is assumed after the last digit. The number is punched so that its last digit is in either column 12, 24, 36, 48, 60, or 72 depending on whether it is the 1st, 2nd, 3rd, 4th, 5th, or 6th piece of information on the card.

FORMAT 2. Floating point (E12.5). The decimal point must appear in the number. The exponent may appear in addition if the number is too large. The last digit describing the number must appear in either column 12, 24, 36, 48, 60, or 72 depending on whether it is the 1st, 2nd, 3rd, 4th, 5th, or 6th piece of information on the card.

(Example: -36. could appear as -0.36+2 or -36.+0 or -36. or -3.6+1 and +0.021 could appear as 0.21-1 or 0.021 or 21.-3 or 0.021.)

FORMAT 3. Octal (012). The octal number is the same as the fixed point number, but the number is an octal number; i.e. a number to the base 8.

C. CONTINUATION OF INPUT ON MORE THAN ONE CARD TYPE

Information being inputed may occupy more than one card of a particular type. If this is the case, more than one card of a particular type may be used. As an example consider Card Type 6 which describes the number of isotope in each material. If there are 9 materials, containing respectively 1, 2, 3, 4, 5, 6, 5, 4, 3 isotopes, then there would be two Card Type 6 input cards. The first card would describe the first 6 materials and would have the numbers 1, 2, 3, 4, 5, 6 in columns 12, 24, 36, 48, 60, 72, respectively, and the second card would describe the last three materials and would have 5, 4, 3 in columns 12, 24, 36, respectively.

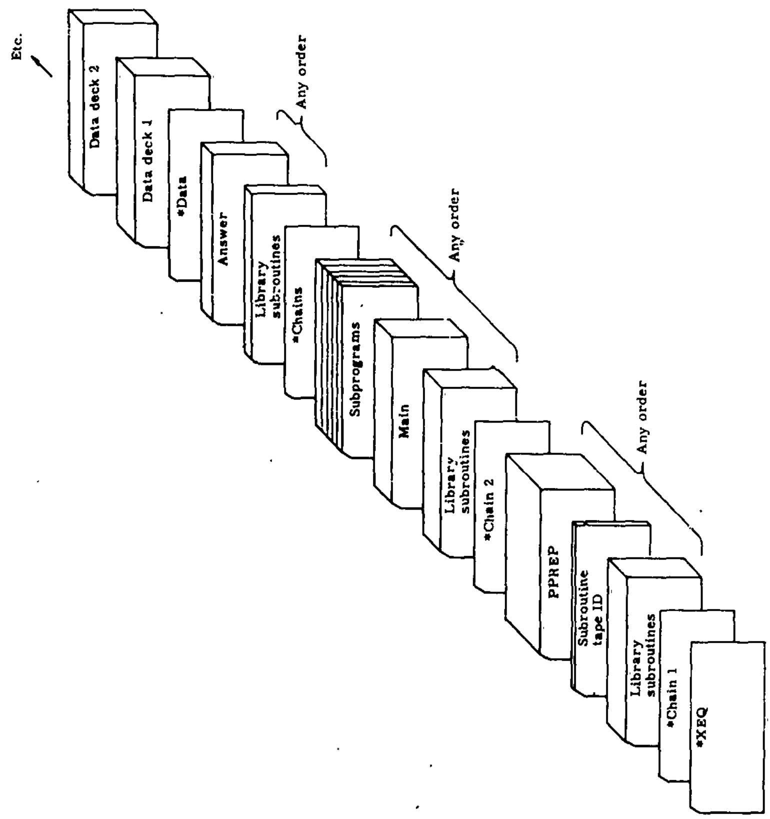


Fig. 2. Sequence of GMCM-9 Deck

D. TRADING STORAGE

It is possible that the problem will stop before a single particle history has been followed because the storage requirements have exceeded 18,000 words. This situation can be remedied by rearranging the problem to reduce the storage requirements. The problem can be rearranged by:

(1) Reducing some of the regions.

(2) Deleting the request for answers which may be of little importance to the user and which require large blocks of information such as:

(a) The number of neutrons scattered elastically, inelastically versus material and energy group.

(b) The number of neutrons from fission versus material and energy group.

(c) The neutron flux versus region and energy group.

(3) Reducing the number of materials and/or isotopes and/or energy groups.

E. INPUT DESCRIPTION

The input forms (Pages 32 to 78) describe the information to be inputed, the format of each piece of input data, the physical units (if any) of the input data, the symbol used in the code to represent the data, and the order in which the data must be entered to perform a calculation. In addition, where arrays of data must be inputed, auxiliary information is included with the input forms to aid in establishing the order of the input cards for these arrays. Columns 73 to 80 of the input cards may be used to identify the information on the card. A suggested method of identification is the card type number which appears on the left of the input forms.

CARD TYPE							
1	WORD	1	2	3	4	5	6
	COLUMNS	1-12	13-24	25-36	37-48	49-60	61-72
	FORMAT	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point
	DESCRIPTION	Logical designation of output tape unit	Logical designation of input tape unit	Logical designation of cross-section tape unit	Logical designation of initial value tape unit (or census tape from previous problem)	Logical designation of breeder tape unit	Logical designation of fission tape unit
	UNITS	None	None	None	None	None	None
	SYMBOL	M10	M9	M8	M7	M6	M5

CARD TYPE	WORD	1	2	3	4	5	6
1	COLUMNS	1-12	13-24	25-36	37-48	49-60	61-72
	FORMAT	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point
	DESCRIPTION	Logical designation of output tape unit	Logical designation of input tape unit	Logical designation of cross-section tape unit	Logical designation of initial value tape unit (or census tape from previous problem)	Logical designation of breeder tape unit	Logical designation of fission tape unit
	UNITS	None	None	None	None	None	None
	SYMBOL	M10	M9	M8	M7	M6	M5

CARD TYPE 2					
	WORD	1	2	3	4
	COLUMNS	1-12	13-24	25-36	37-48
	FORMAT	112 Fixed Point	112 Fixed Point	112 Fixed Point	112 Fixed Point
	DESCRIPTION	Logical designation of census tape unit	Logical designation of chain link tape unit	Logical designation of collision tape unit	Logical designation of inelastic scattering gamma tape unit
	UNITS	None	None	None	None M8 • M6 • M5 • M4 • M1
	SYMBOL	M4	M3	M2	M1

*NOTE: All tapes are used by this code at least once (at start M8, M7, M6, M5, M4, M2, and M1 are rewound) and, therefore, must be assigned an actual unit number. Those tapes that are not to be used later can have the same logical designation; tapes placed in this category are as follows: cross section tape not saved; no breeding; all fission cross sections are zero; census tape not saved; no inelastic gammas on tape.

CARD TYPE 3		
	WORD	
	COLUMNS	2-72
	FORMAT	Hollerith
	DESCRIPTION	
	UNITS	
	SYMBOL	

NOTE: Input 3--card type 3 (three cards with any information desired)

CARD TYPE 4						
	WORD	1	2	3	4	
	COLUMNS	1-12	13-24	25-36	37-48	
	FORMAT	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	O12 Octal	
	DESCRIPTION	NCT = 0 This problem uses an initial value tape from the particle generator. NCT = 1 This problem uses the census tape of a previous problem as the initial value tape. If NCT = 1, omit card type 5 through card type 35.	NOPAE = 0 All answers are straight Monte Carlo. The analytic estimation subroutine is not entered. NOPAE = 1 The analytic estimation subroutine is entered and the appropriate tallies made. These are labeled as analytic estimation answers on the printout.	Total number of particles on the initial value tape (or census tape from previous problem)	Initial octal random number. This is a 12-digit number.	
	UNITS	None	None	None	None	
	SYMBOL	NCT	NOPAE	NIV	S	

CARD TYPE 5	WORD	1	2	3	4	5	6
	COLUMNS	1-12	13-24	25-36	37-48	49-60	61-72
	FORMAT	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point
	DESCRIPTION	Total number of materials ≤ 10	Total number of isotopes in all materials ≤ 10	Total number of fissionable isotopes $\leq$IMAX These must be the first NFI isotopes for isotope input.	Total number of energy groups ≤ 32	Total number of regions ≤ 300	Total number of surfaces for all regions (total number of equations describing all distinct surfaces).
	UNITS	None	None	None	None	None	None
	SYMBOL	MMAX	IMAX	NFI	JMAG	NRMAX	NSTOT

CARD TYPE 6						
WORD	1	2		M		MMAX
COLUMNS	1-12	13-24				
FORMAT	I12 Fixed Point	I12 Fixed Point		I12 Fixed Point		I12 Fixed Point
DESCRIPTION	Number of isotopes in Material No. 1	Number of isotopes in Material No. 2		Number of isotopes in Material No. M		Number of isotopes in the last material
UNITS	None	None		None		None
SYMBOL	NIMAX(1)	NIMAX(2)		NIMAX(M)		NIMAX(MMAX)

CARD TYPE 7

	1	2		NR		NRMAX
WORD	1	2		NR		NRMAX
COLUMNS	1-12	13-24				
FORMAT	I12 Fixed Point	I12 Fixed Point		I12 Fixed Point		I12 Fixed Point
DESCRIPTION	Number of surfaces bounding Region No. 1	Number of surfaces bounding Region No. 2		Number of surfaces bounding Region No. NR		Number of surfaces bounding the last region.
UNITS	None	None		None		None
SYMBOL	NSMAX(1)	NSMAX(2)		NSMAX(NR)		NSMAX(NRMAX)

CARD TYPE 8						
	WORD	1	2	3	4	5
	COLUMNS	1-12	13-24	25-36	37-48	49-60
	FORMAT	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point
	DESCRIPTION	Number of region pairs for which boundary crossings will be tallied (tallies are straight Monte Carlo if NOPAE = 0) ≤ 10 If MREGM = 0 omit card type 11.	Number of materials for which the number of neutrons from elastic and inelastic scattering and fission are to be tallied by energy group (tallies are straight Monte Carlo if NOPAE = 0) ≤ 10 If MMM = 0 omit card type 12	Number of regions for which the flux will be calculated (tallies are straight Monte Carlo if NOPAE = 0) ≤ 20 If MMAEF = 0 omit card type 13.	<u>NFISF = 0</u> Three particles are generated from the fission interaction <u>NFISF = 1</u> JMAG particles are generated from the fission interaction	<u>NGAM = 0</u> No calculation is made for the inelastic scattering gammas. <u>NGAM = 1</u> The energy, X, Y, Z coordinates, and weight of the gamma are saved on tape M1 (it is not processed in any form).
	UNITS	None	None	None	None	None
	SYMBOL	MREGM	MMM	MMAEF	NFISF	NGAM

CARD TYPE P

WORD	1	2	3	4	
COLUMNS	1-12	13-24	25-36	37-48	
FORMAT	E12.5 Floating Point	E12.5 Floating Point	E12.5 Floating Point	E12.5 Floating Point	
DESCRIPTION	Census time The coordinates of particles surviving to this time are saved on the census tape, and the next particle is followed.	Weight cutoff Particles of weight < DELW are saved or rejected by playing Russian roulette with their weight.	Limit at which approximations will be made for scattered particle's velocity and direction cosines.	Small distance added to the distance a particle travels in escaping a region. The purpose of this is to ensure that the part...e coordinates are in the region entered. Suggested value is some number less than 0.0001	
UNITS	Microseconds	None	Atomic Mass Units	Centimeters	
SYMBOL	CT	DELW	APRLIE	EPSLON	

CARD TYPE 10					
	WORD	1	2	3	
	COLUMNS	1-12	13-24	25-36	
	FORMAT	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	
	DESCRIPTION	First special tally region (STR). Tally is straight Monte Carlo if NOPAE = 0.	Second STR	Third STR	
	UNITS	None	None	None	
	SYMBOL	NSTR(1)	NSTR(2)	NSTR(3)	

NOTE:

NSTR(3) > NSTR(2)
NSTR(2) > NSTR(1)
Input in increasing order.

CARD TYPE 11						
WORD	1	2	2*IMI-1	2*IMI	2*MREGM-1	2*MREGM
COLUMNS	1-12	13-24				
FORMAT	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point
DESCRIPTION	Region which particle leaves	Region which particle enters	Region which particle leaves	Region which particle enters	Region which particle leaves	Region which particle enters
	First region pair for which tally of boundary crossings will be made (tallies are straight Monte Carlo if NOPAE = 0)		IMIth region pair for which tally of boundary crossings will be made NOTE: MLOREG(IMI) > MLOREG(IMI-1) If MLOREG(IMI) = MLOREG(IMI-1 Then, MHIREG(IMI) > MHIREG(IMI-1).		Last region pair for which tally of boundary crossings will be made Example: MREGM = 5 IMI MLOREG MHIREG 1 1 8 2 2 1 3 2 7 4 2 8 5 8 1	
UNITS	None	None	None	None	None	None
SYMBOL	MLOREG(1)	MHIREG(1)	MLOREG(IMI)	MHIREG(IMI)	MLOREG(MREGM)	MHIREG(MREGM)

NOTE: If MREGM = 0, omit card type 11 MREGM is on card type 8.

CARD TYPE 12

	WORD	1	2		IMI		MMM
CARD TYPE 12	COLUMNS	1-12	13-24				
	FORMAT	I12 Fixed Point	I12 Fixed Point		I12 Fixed Point		I12 Fixed Point
	DESCRIPTION	First material for which tallies of neutrons from elastic and inelastic scatter and fission will be made (tallies are straight Monte Carlo if NOPAE = 0)	Second material for which tallies will be made. NOTE: IMM(2) > IMM(1)		IMIth material for which tallies will be made. NOTE: IMM(IMI) > IMM(IMI-1)		Last material for which tallies will be made.
	UNITS	None	None		None		None
	SYMBOL	IMM(1)	IMM(2)		IMM(IMI)		IMM(MMM)

NOTE: If MMM = 0, omit card 12. MMM is on card type 8.

CARD TYPE 13							
	WORD	1	2	2*IMI-1	2*IMI	2*MMAEF-1	2*MMAEF
	COLUMNS	1-12	13-24				
	FORMAT	I12 Fixed Point	E12.5 Floating Point	I12 Fixed Point	E12.5 Floating Point	I12 Fixed Point	E12.5 Floating Point
	DESCRIPTION	First region for which the flux will be calculated (answers are straight Monte Carlo if NO) PAE = 0	Volume of the first region	IMIth region for which the flux will be calculated NOTE. MREG(IMI) ≥ MREG(IMI-1)	Volume of the IMIth region	Last region for which the flux will be calculated	Volume of the last region
	UNITS	None	Centimeters^3	None	Centimeters^3	None	Centimeters^3
	SYMBOL	MREG(1)	VOL(1)	MREG(IMI)	VOL(IMI)	MREG(MMAEF)	VOL(MMAEF)

NOTE: If MMAEF = 0, omit card 13. MMAEF is on card type 8.

CARD TYPE 14						
	WORD	1	2	3	4	5
	COLUMNS	1-12	13-24	25-36	37-48	49-60
	FORMAT	I12 Fixed Point	E12.5 Floating Point	E12.5 Floating Point	E12.5 Floating Point	E12.5 Floating Point
	DESCRIPTION	Surface type <u>NT(NS) = 1</u> $AX^2 + X_0X + BY^2 +$ $Y_0Y + CZ^2 + Z_0Z - K = 0$ <u>NT(NS) = 2</u> $A(X - X_0)^2 + B(Y - Y_0)^2$ $+ C(Z - Z_0)^2 - K = 0$ <u>NT(NS) = 3</u> $(X - X_0)^2 + (Y - Y_0)^2 - K = 0$ <u>NT(NS) = 4</u> $X - K = 0$ <u>NT(NS) = 5</u> $Y - K = 0$ <u>NT(NS) = 6</u> $Z - K = 0$ <u>NT(NS) = 7</u> $X - X_0 + Y - Y_0 + Z - Z_0$ $-K = 0$	<u>A</u> in the equation of the surface	<u>B</u> in the equation of the surface	<u>C</u> in the equation of the surface	<u>K</u> in the equation of the surface
	UNITS	None	None	None	None	Centimeters[1 or 2]
	SYMBOL	NT(NS)	AC(NS)	BC(NS)	CC(NS)	XK(NS)

NOTE: Input card 14 and card 15 for NS = 1, 2, ..., NSTOT (NSTOT is on card type 5) in the order: 14, 15 (NS = 1); 14, 15 (NS = 2); 14, 15 (NS = 3); ...; 14, 15 (NS = NS); ...; 14, 15 (NS = NSTOT). See page following card type 15.

CARD TYPE 15	WORD	1	2	3	
	COLUMNS	1-12	13-24	25-36	
	FORMAT	E12.5 Floating Point	E12.5 Floating Point	E12.5 Floating Point	
	DESCRIPTION	X_0 in the equation of the surface	Y_0 in the equation of the surface	Z_0 in the equation of the surface	
	UNITS	Centimeters	Centimeters	Centimeters	
	SYMBOL	XZ(NS)	YZ(NS)	ZZ(NS)	

NOTE: Input card 14 and card 15 for NS = 1, 2, ..., NSTOT (NSTOT is on card type 5) in the order: $\underbrace{14,\ 15}_{NS=1}$; $\underbrace{14,\ 15}_{NS=2}$; $\underbrace{14,\ 15}_{NS=3}$; ...; $\underbrace{14,\ 15}_{NS=NS}$, ...; $\underbrace{14,\ 15}_{NS=NSTOT}$

Order of Input: Card Type 14 and Card Type 15

Symbol	Definition
NS	Surface number (in the list of unique surfaces)
NT(NS)	Surface type (see Card Type 14, the first word)
AC(NS)	A in the equation of the surface
BC(NS)	$\overline{B}$ in the equation of the surface
CC(NS)	$\overline{C}$ in the equation of the surface
XK(NS)	$\overline{K}$ in the equation of the surface
XZ(NS)	$\overline{X}_0$ in the equation of the surface
YZ(NS)	$\overline{Y}_0$ in the equation of the surface
ZZ(NS)	$\overline{Z}_0$ in the equation of the surface

Card	Quantities on Card					
Card Type 14	NT(1)	AC(1)	BC(1)	CC(1)	XX(1)	NS = 1
Card Type 15	XZ(1)	YZ(1)	ZZ(1)			
Card Type 14	NT(2)	AC(2)	BC(2)	CC(2)	XX(2)	NS = 2
Card Type 15	XZ(2)	YZ(2)	ZZ(2)			
	⋮	⋮	⋮	⋮		
Card Type 14	NT(NS)	AC(NS)	CC(NS)	CC(NS)	XK(NS)	NS = NS
Card Type 15	XZ(NS)	YZ(NS)	ZZ(NS)			
	⋮	⋮	⋮	⋮		
Card Type 14	NT(NSTOT)	AC(NSTOT)	CC(NSTOT)	CC(NSTOT)	XK(NSTOT)	NS = NSTOT
Card Type 15	XZ(NSTOT)	YZ(NSTOT)	ZZ(NSTOT)			

CARD TYPE 16						
	WORD	1	2	3	4	
	COLUMNS	1-12	13-24	25-36	37-48	
	FORMAT	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	
	DESCRIPTION	Material number of this region	<u>NAB(NR) = 0</u> This region does not have ambiguous boundaries. <u>NAB(NR) = 1</u> This region has ambiguous boundaries (these must be the first two surfaces of this region described by card types 17)	<u>NOR(NR) = 0</u> This region is an inside region. <u>NOR(NR) = 1</u> This region is an outside region (particles entering an outside region are said to have escaped from the system)	Number of particles per collision in this region (splitting) If the collision is a scatter NPFC(NR) particles are generated. If the collision is a fission and: <u>NFISF = 0</u> 3*NPFC(NR) particles are followed <u>NFISF = 1</u> JMAG*NPFC(NR) particles are followed NPFC(NR) ≥ 1	
	UNITS	None	None	None	None	
	SYMBOL	MN(NR)	NAB(NR)	NOR(NR)	NPFC(NR)	

NOTE. Input card type 16 and card types 17 for NR = 1, 2, ..., NRMAX in the order $\underbrace{16, \underbrace{17, 17, \ldots, 17}_{NSMAX(1)}}_{NR = 1}; \underbrace{16, \underbrace{17, 17, \ldots, 17}_{NSMAX(2)}}_{NR = 2}; \underbrace{16, \underbrace{17, 17, \ldots, 17}_{NSMAX(NR)}}_{NR = NR}; \underbrace{16, \underbrace{17, 17, \ldots, 17}_{NSMAX(NRMAX)}}_{NR = NRMAX}$ See additional page following card type 17.

CARD TYPE 17	WORD	1	2	3	4	5	6
	COLUMNS	1-12	13-24	25-36	37-48	49-60	61-72
	FORMAT	I12 Fixed Point	E12.5 Floating Point	E12.5 Floating Point	E12.5 Floating Point	E12.5 Floating Point	E12.5 Floating Point
	DESCRIPTION	AI(NS, NR) = +1, For a particle inside region NR, R(NS) > 0. AI(NS, NR) = -1, R(NS) = the equation of surface NS of region NR evaluated at the coordinates of the particle	The number of surface NS in the list of surfaces bounding all regions	First most probable next region for a particle leaving region NR through surface NS	Second most probable next region for a particle leaving region NR through surface NS	Third most probable next region for a particle leaving region NR through surface NS	Fourth most probable next region for a particle leaving region NR through surface NS
	UNITS						
	SYMBOL	AI(NS, NR)	NOS(NS, NR)	MP(1, NS, NR)	MP(2, NS, NR)	MP(3, NS, NR)	MP(4, NS, NR)

NOTE: Input card 16 and card types 17 for NR = 1, 2, ..., NRMAX in the order: $16, \underbrace{\overbrace{17, 17, \ldots, 17}^{NSMAX(1)}}_{NR = 1}, 16, \underbrace{\overbrace{17, 17, \ldots, 17}^{NSMAX(2)}}_{NR = 2}, \ldots; 16, \underbrace{\overbrace{17, 17, \ldots, 17}^{NSMAX(NR)}}_{NR = NR}, \ldots 16, \underbrace{\overbrace{17, 17, \ldots, 17}^{NSMAX(NRMAX)}}_{NR = NRMAX}$. See page following card type 17.

Order of Input: card type 16 and card type 17

For symbols and definitions, see card type 16 and card type 17

Card		Quantities on the Card					
Card Type 16	NR = 1	MN(1)	NAB(1)	NOR(1)	NPFC(1)		
Card Type 17		AI(1, 1)	NOS(1, 1)	MP(1, 1, 1)	MP(2, 1, 1)	MP(3, 1, 1)	MP(4, 1, 1)
Card Type 17		AI(2, 1)	NOS(2, 1)	MP(1, 2, 1)	MP(2, 2, 1)	MP(3, 2, 1)	MP(4, 2, 1)
⋮		⋮	⋮	⋮	⋮	⋮	⋮
Card Type 17		AI(NS, 1)	NOS(NS, 1)	MP(1, NS, 1)	MP(2, NS, 1)	MP(3, NS, 1)	MP(4, NS, 1)
⋮		⋮	⋮	⋮	⋮	⋮	⋮
Card Type 17		AI(NSMAX(1), 1)	NOS(NSMAX(1), 1)	MP(1, NSMAX(1), 1)	MP(2, NSMAX(1), 1)	MP(3, NSMAX(1), 1)	MP(4, NSMAX(1), 1)
Card Type 16	NR = 2	MN(2)	NAB(2)	NOR(2)	NPFC(2)		
Card Type 17		AI(1, 2)	NOS(1, 2)	MP(1, 1, 2)	MP(2, 1, 2)	MP(3, 1, 2)	MP(4, 1, 2)
⋮		⋮	⋮	⋮	⋮	⋮	⋮
Card Type 17		AI(NS, 2)	NOS(NS, 2)	MP(1, NS, 2)	MP(2, NS, 2)	MP(3, NS, 2)	MP(4, NS, 2)
⋮		⋮	⋮	⋮	⋮	⋮	⋮
Card Type 17		AI(NSMAX(2), 2)	NOS(NSMAX(2), 2)	MP(1, NSMAX(2), 2)	MP(2, NSMAX(2), 2)	MP(3, NSMAX(2), 2)	MP(4, NSMAX(2), 2)
⋮		⋮	⋮	⋮	⋮	⋮	⋮
Card Type 16	NR = NR	MN(NR)	NAB(NR)	NOR(NR)	NPFC(NR)		
Card Type 17		AI(1, NR)	NOS(1, NR)	MP(1, 1, NR)	MP(2, 1, NR)	MP(3, 1, NR)	MP(4, 1, NR)
⋮		⋮	⋮	⋮	⋮	⋮	⋮
Card Type 17		AI(NS, NR)	NOS(NS, NR)	MP(1, NS, NR)	MP(2, NS, NR)	MP(3, NS, NR)	MP(4, NS, NR)
⋮		⋮	⋮	⋮	⋮	⋮	⋮
Card Type 17		AI(NSMAX(NR), NR)	NOS(NSMAX(NR), NR)	MP(1, NSMAX(NR), NR)	MP(2, NSMAX(NR), NR)	MP(3, NSMAX(NR), NR)	MP(4, NSMAX(NR), NR)
⋮		⋮	⋮	⋮	⋮	⋮	⋮
Card Type 16	NR = NRMAX	MN(NRMAX)	NAB(NRMAX)	NOR(NRMAX)	NPFC(NRMAX)		
Card Type 17		AI(1, NRMAX)	NOS(1, NRMAX)	MP(1, 1, NRMAX)	MP(2, 1, NRMAX)	MP(3, 1, NRMAX)	MP(4, 1, NRMAX)
⋮		⋮	⋮	⋮	⋮	⋮	⋮
Card Type 17		AI(NS, NRMAX)	NOS(NS, NRMAX)	MP(1, NS, NRMAX)	MP(2, NS, NRMAX)	MP(3, NS, NRMAX)	MP(4, NS, NRMAX)
⋮		⋮	⋮	⋮	⋮	⋮	⋮
Card Type 17		AI(NSMAX(NRMAX), NRMAX)	NOS(NSMAX(NRMAX), NRMAX)	MP(1, NSMAX(NRMAX), NRMAX)	MP(2, NSMAX( ), NRMAX)	MP(3, NSMAX( ), NRMAX)	MP(4, NSMAX( ), NRMAX)

CARD TYPE 18.

WORD	1	2		M		MMAX
COLUMNS	1-12	13-24				
FORMAT	I12 Fixed Point	I12 Fixed Point		I12 Fixed Point		I12 Fixed Point
DESCRIPTION	NBREED(1) = 0 no breeding isotope in Material No. 1 NBREED(1) ≠ 0 The first isotope of Material No. 1 (specified on card 19) undergoes breeding	Similarly for Material No. 2		Similarly for Material No. M		Similarly for the last material
UNITS	None	None		None		None
SYMBOL	NBREED(1)	NBREED(2)		NBREED(M)		NBREED(MMAX)

CARD TYPE 18						
WORD	1	2		NI		NIMAX(M)
COLUMNS	1-12	13-24				
FORMAT	I12 Fixed Point	I12 Fixed Point		I12 Fixed Point		I12 Fixed Point
DESCRIPTION	Number of the first isotope of Material No. M in the list of isotopes NOTE: Fissionable isotopes must be listed first (if any)	Number of the second isotope of Material No. M in the list of isotopes		Similarly Nith isotope of Material No. M		Number of the last isotope o. Material No. M in the list of isotopes
UNITS	None	None		None		None
SYMBOL	K(1,M)	K(2,M)		K(NI,M)		K(NIMAX(M),M)

NOTE: Input card 18 for M = 1, 2, ..., MMAX

CARD TYPE 20						
WORD	1	2		I		IMAX
COLUMNS	1-12	13-24				
FORMAT	E12.5 Floating Point	E12.5 Floating Point		E12.5 Floating Point		E12.5 Floating Point
DESCRIPTION	Atomic weight of the first isotope in the list of all isotopes	Atomic weight of the second isotope in the list of all isotopes		Atomic weight of the Ith isotope in the Ith list of all isotopes		Atomic weight of the last isotope in the list of all isotopes
UNITS	Atomic Mass Units	Atomic Mass Units		Atomic Mass Units		Atomic Mass Units
SYMBOL	A(1)	A(2)		A(I)		A(IMAX)

CARD TYPE 21			
	WORD	1	
	COLUMNS	1-12	
	FORMAT	I12 Fixed Point	
	DESCRIPTION	LTEST = 0 Probabilities read in or calculated from input information LTEST = 1 Probabilities read from cross-section tape M8 (previous card input for materials and isotopes must agree with that for which this tape was generated. Omit card 22 through card 27).	For LTEST = 0 Input card type 22, card type 23, and card type 24 in the following order $\underbrace{\underbrace{22, 22, \ldots, 22}_{JMAG}, 23, 24}_{I=1}; \underbrace{\underbrace{22, 22, \ldots, 22}_{JMAG}, 23, 24}_{I=2}; \ldots; \underbrace{\underbrace{22, 22, \ldots, 22}_{JMAG}, 23, 24}_{I=NPI};$ $\underbrace{\underbrace{22, 22, \ldots, 22}_{JMAG}}_{I=NPI+1}; \underbrace{\underbrace{22, 22, \ldots, 22}_{JMAG}}_{I=NPI+2}; \ldots; \underbrace{\underbrace{22, 22, \ldots, 22}_{JMAG}}_{I=IMAX}$ See page following card type 24.
	UNITS	None	
	SYMBOL	LTEST	

CARD TYPE 22							
	WORD	1	2		J'		J
	COLUMNS	1-12	13-24				
	FORMAT	E12.5 Floating Point	E12.5 Floating Point		E12.5 Floating Point		E12.5 Floating Point
	DESCRIPTION	Probability of scattering from energy Group J to energy Group 1 (probabilities for center of mass coordinates) $P(1,J,I) \leq 1.$	Probability of scattering from energy Group J to energy Group 2. (Probabilities for center of mass coordinates)		Similarly energy Group J' $P(J',J,I) \geq P(J'+1,J,I)$		Probability of scattering from energy Group J to energy Group J (probability of remaining in the same energy group) $P(J,J,I) \geq 0.$
	UNITS	None	None		None		None
	SYMBOL	P(1,J,I)	P(2, J, I)		P(J',J,I)		P(J,J,I)

NOTE: Input card 22 for J = 1,2,..., JMAG
Omit if LTEST = 1

CARD TYPE 23							
	WORD	1	2		J		JMAX
	COLUMNS	1-12	13-24				
	FORMAT	E12.5 Floating Point	E12.5 Floating Point		E12.5 Floating Point		E12.5 Floating Point
	DESCRIPTION	Fission spectrum probability of neutron being born at energy level No. 1 or below NOTE: $FS(1,I) = 0.$	Fission spectrum probability of neutron being born at energy level No. 2 or below		Fission spectrum probability of neutron being born at energy level No. J or below NOTE: $FS(J,I) \leq FS(J+1,I)$		Fission spectrum, probability of neutron being born at energy level JMAX (= JMAG + 1) or below $FS(JMAX) = 1.$
	UNITS	None	None		None		None
	SYMBOL	FS(1,I)	FS(2,I)		FS(J,I)		FS(JMAX,I)

NOTE: Omit if LTEST = 1
Omit if I > NFI

CARD TYPE 24							
	WORD	1	2		J		JMAG
	COLUMNS	1-12	13-24				
	FORMAT	E12.5 Floating Point	E12.5 Floating Point		E12.5 Floating Point		E12.5 Floating Point
	DESCRIPTION	Neutron yield for fission of isotope I with incident neutron in energy Group 1	Neutron yield for fission of isotope I with incident neutron in energy Group 2		Similarly for incident neutron in energy Group J		Similarly for incident neutron in the highest energy group, JMAG
	UNITS	Neutrons/Fission	Neutrons/Fission		Neutrons/Fission		Neutrons/Fission
	SYMBOL	PNU(1,I)	PNU(2,I)		PNU(J,I)		PNU(JMAG,I)

NOTE: Omit if LTEST = 1
Omit if I > NPI

CARD TYPE 25							
	WORD	1	2		M		MMAX
	COLUMNS	1-12	13-24				
	FORMAT	E12.5 Floating Point	E12.5 Floating Point		E12.5 Floating Point		E12.5 Floating Point
	DESCRIPTION	Density of Material No. 1	Density of Material No. 2		Density of Material No. M		Density of the last material
	UNITS	$Grams/CM^3$	$Grams/CM^3$		$Grams/CM^3$		$Grams/CM^3$
	SYMBOL	RHO(1)	RHO(2)		RHO(M)		RHO(MMAX)

Order of Input: Card Type 22, Card Type 23, and Card Type 24

For definitions of symbols, see the appropriate cards

Card	Quantities on the Card				
Card Type 22	P(1, 1, 1)				I = 1
Card Type 22	P(1, 2, 1)	P(2, 2, 1)			
⋮	⋮	⋮			
Card Type 22	P(1, J, 1)	P(2, J, 1)	. . . P(J', J, 1)	. . . P(J, J, 1)	
⋮	⋮	⋮	⋮	⋮	
Card Type 22	P(1, JMAG, 1)	P(2, JMAG, 1)	. . . P(J', JMAG, 1)	. . . P(JMAG, JMAG, 1)	
Card Type 23	FS(1, 1)	FS(2, 1)	. . . FS(J, 1)	. . . FS(JMAG, 1)	
Card Type 24	PNU(1, 1)	PNU(2, 1)	. . . PNU(J, 1)	. . . PNU(JMAG, 1)	
⋮					⋮
Card Type 22	P(1, 1, NFI)				I = NFI
⋮	⋮				
Card Type 22	P(1, J, NFI)	P(2, J, NFI)	. . . P(J', J, NFI)	. . . P(J, J, NFI)	
⋮	⋮	⋮	⋮	⋮	
Card Type 22	P(1, JMAG, NFI)	P(2, JMAG, NFI)	. . . P(J', JMAG, NFI)	. . . P(JMAG, JMAG, NFI)	
Card Type 23	FS(1, NFI)	FS(2, NFI)	. . . FS(J, NFI)	. . . FS(JMAX, NFI)	
Card Type 24	PNU(1, NFI)	PNU(2, NFI)	. . . PNU(J, NFI)	. . . PNU(JMAG, NFI)	
Card Type 22	P(1, 1, NFI + 1)				I = NFI + 1
⋮	⋮				
Card Type 22	P(1, J, NFI + 1)	P(2, J, NFI + 1)	. . . P(J', J, NFI + 1)	. . . P(J, J, NFI + 1)	
⋮	⋮	⋮	⋮	⋮	
Card Type 22	P(1, JMAG, NFI + 1)	P(2, JMAG, NFI + 1)	. . . P(J', JMAG, NFI + 1)	. . . P(JMAG, JMAG, NFI + 1)	
⋮					⋮
Card Type 22	P(1, 1, IMAX)				I = IMAX
⋮	⋮				
Card Type 22	P(1, J, IMAX)	P(2, J, IMAX)	. . . P(J', J, IMAX)	. . . P(J, J, IMAX)	
⋮	⋮	⋮	⋮	⋮	
Card Type 22	P(1, JMAG, IMAX)	P(2, JMAG, IMAX)	. . . P(J', JMAG, IMAX)	. . . P(JMAG, JMAG, IMAX)	

CARD TYPE 26							
	WORD	1	2		NI		NIMAX(M)
	COLUMNS	1-12	13-24				
	FORMAT	E12.5 Floating Point	E12.5 Floating Point		E12.5 Floating Point		E12.5 Floating Point
	DESCRIPTION	Weight fraction of the first isotope of Material No. M	Weight fraction of the second isotope of Material No. M		Weight fraction of the NIth isotope of Material No. M		Weight fraction of the last isotope of Material No. M
	UNITS	None	None		None		None
	SYMBOL	WTF(1, M)	WTF(2, M)		WTF(NI, M)		WTF(NIMAX(M), M)

NOTE: Input Card Type 26 for M = 1, 2, ..., MMAX

CARD TYPE 27						
	WORD	1	2	3	4	
	COLUMNS	1-12	13-24	25-36	37-48	
	FORMAT	E12.5 Floating Point	E12.5 Floating Point	E12.5 Floating Point	E12.5 Floating Point	
	DESCRIPTION	Elastic scattering cross section for energy Group J of isotope I	Inelastic scattering cross section for energy Group J of isotope I	Fission cross section for energy Group J of isotope I	Capture cross section for energy Group J of isotope I	
	UNITS	Barns	Barns	Barns	Barns	
	SYMBOL	SEL(J, I)	SIN(J, I)	SFIS(J, I)	SCAP(J, I)	

NOTE: Input Card Type 27 for J = 1,2,..., JMAG; I = 1,2,...IMAX in the order: $\underbrace{\underbrace{27,\ldots,27}_{JMAG}}_{I=1}; \underbrace{\underbrace{27,\ldots,27}_{JMAG}}_{I=2}; \ldots; \underbrace{\underbrace{27,\ldots,27}_{JMAG}}_{I=I}; \ldots; \underbrace{\underbrace{27,\ldots,27}_{JMAG}}_{I=IMAX}$

Further details on the order of card type 27 can be found on the page following card type 27

CARD TYPE 28						
	WORD	1	2		J		JMAX
	COLUMNS	1-12	13-24				
	FORMAT	E12.5 Floating Point	E12.5 Floating Point		E12.5 Floating Point		E12.5 Floating Point
	DESCRIPTION	Energy level No. 1	Energy level No. 2 VSC(2) > VSC(1)		Energy level No. J VSC(J) > VSC(J-1)		Last (and highest) energy level
	UNITS	Electron Volts	Electron Volts		Electron Volts		Electron Volts
	SYMBOL	VSC(1)	VSC(2)		VSC(J)		VSC(JMAX)

CARD TYPE 29			
	WORD	1	
	COLUMNS	1-12	
	FORMAT	I12 Fixed Point	
	DESCRIPTION	Number of cases of generator input. <u>NKASE = 0</u> Generator bypassed (use a previously generated IV tape--<u>cannot</u> use the census tape of a previous problem) <u>NKASE > 0</u> Input NKASE sets of cards 30 through 35	
	UNITS	None	
	SYMBOL	NKASE	

Order of Input: Card Type 27

Symbols	Definition
J	Energy group
I	Isotope number (in list of unique isotopes)
SEL(J, I)	Elastic scattering cross section (energy group J, isotope I)
SIN(J, I)	Inelastic scattering cross section (energy group J, isotope I)
SFIS(J, I)	Fission cross se-tion (energy group J, isotope I)
SCAP(J, I)	Capture cross section (energy group J, isotope I)

Number of Card Type 27		Quantities on Card			
1		SEL(1, 1)	SIN(1, 1)	SFIS(1, 1)	SCAP(1, 1)
J	I = 1	SEL(J, 1)	SIN(J, 1)	SFIS(J, 1)	SCAP(J, 1)
JMAG		SEL(JMAG, 1)	SIN(JMAG, 1)	SFIS(JMAG, 1)	SCAP(JMAG, 1)
JMAG + 1		SEL(1, 2)	SIN(1, 2)	SFIS(1, 2)	SCAP(1, 2)
JMAG + J	I = 2	SEL(J, 2)	SIN(J, 2)	SFIS(J, 2)	SCAP(J, 2)
2*JMAG		SEL(JMAG, 2)	SIN(JMAG, 2)	SFIS(JMAG, 2)	SCAP(JMAG, 2)
(I - 1)*JMAG + 1		SEL(1, I)	SIN(1, I)	SFIS(1, I)	SCAP(1, I)
(I - 1)*JMAG + J	I = I	SEL(J, I)	SIN(J, I)	SFIS(J, I)	SCAP(J, I)
I*JMAG		SEL(JMAG, I)	SIN(JMAG, I)	SFIS(JMAG, I)	SCAP(JMAG, I)
(IMAX - 1)*JMAG + 1		SEL(1, MAX)	SIN(1, IMAX)	SFIS(1, IMAX)	SCAP(1, IMAX)
(IMAX - 1)*JMAG + J	I = IMAX	SEL(J, IMAX)	SIN(J, IMAX)	SFIS(., IMAX)	SCAP(J, IMAX
IMAX*JMAG		SEL(JMAG, IMAX)	SIN(JMAG, IMAX)	SFIS(JMAG, IMAX)	SCAP(JMAG, IMAX)

CARD TYPE 30	WORD	1	2	3	4	5	6
	COLUMNS	1-12	13-24	25-36	37-48	49-60	61-72
	FORMAT	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point
	DESCRIPTION	Determines selection of X, Y, Z of particles NA = 1 Uses Tables 1, 2, 3. Can set IMX(4) = 0 NA = 2 Uses Tables 1 and 4. Can set IMX(2), IMX(3) = 0 NA = 3, 4 Uses Tables 1 and 4. Can set IMX(2), IMX(3) = 0 NA = 5 Uses Table 1. Can set IMX(2), IMX(3), IMX(4) = 0	Determines selection of direction cosines of particle NE = 1 α, β, γ chosen isotropically. Can set IMX(6), IMX(7) = 0 NE = 2 Uses Table 5. Can set IMX(7) = 0 NE = 3 Uses Tables 6 and 7	Determines selection of time at which particle is born NH = 0 Time at birth = 0 NH = 1 Time at birth = ξ·TIN ξ = random number 0 < ξ < 1	Region in which particles are born	Total number of particles on the IV tape at the end of this generator case (= total number of particles generated from previous cases and number to be generated by this case).	NTRA = 0 X, Y, Z written on tape as calculated in the generated NTRA = 1 X, Y, Z each translated by XZRO, YZRO, and ZZRO before writing on IV tape
	UNITS	None	None	None	None	None	None
	SYMBOL	NA	NE	NH	NKIN	NPIV	NTRA

CARD TYPE 31							
	WORD	1	2	3	4	5	
	COLUMNS	1-12	13-24	25-36	37-48	49-60	
	FORMAT	E12.5 Floating Point	E12.5 Floating Point	E12.5 Floating Point	E12.5 Floating Point	E12.5 Floating Point	
	DESCRIPTION	Input time. NH = 0 Input time not used NH = 1 Time at which particle is born = ξ*TIN	Number of neutrons represented by each particle generated	Translation in X-direction	Translation in Y-direction	Translation in Z-direction	
	UNITS	Microseconds	None	Centimeters	Centimeters	Centimeters	
	SYMBOL	TIN	WIN	XZRO	YZRO	ZZRO	

CARD TYPE 32						
WORD	1	2	3	4	5	6
COLUMNS	1-12	13-24	25-36	37-48	49-60	61-70
FORMAT	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point	I12 Fixed Point
DESCRIPTION	Number of entries in L-Tables used to find Z coordinate of particles NA = 1, 2, 3, 4 ≤ 300	Number of entries in M-Tables used to find X coordinate of particles NA = 1 ≤ 300	Number of entries in N-Tables used to find Y coordinate of particles NA = 1 ≤ 300	Number of entries in O-Tables used to find ρ, X Y; NA = 2, 3, 4 used to find r, X, Y, Z; IA = 5 ≤ 300	Number of entries in P-Tables used to find velocity and energy group of particles NOTE: IMX(5) $\leq$ JMAX	Number of entries in R-Tables used to find Y: NE = 2, 3 ≤ 300
UNITS						
SYMBOL	IMX(1)	IMX(2)	IMX(3)	IMX(4)	IMX(5)	IMX(6)

CARD TYPE 33		
WORD	1	
COLUMNS	1-12	
FORMAT	I12 Fixed Point	
DESCRIPTION	Number of entries in S-Tables used to find S; NE ≥ 3 ≤ 300	
UNITS	None	
SYMBOL	IMX(7)	

CARD TYPE 34						
WORD	1	2		I		IMX(J)
COLUMNS	1-12	13-24				
FORMAT	E12.5 Floating Point	E12.5 Floating Point		E12.5 Floating Point		E12.5 Floating Point
DESCRIPTION	Cumulative probability for entry QP(J,1) in the table of coordinates (card type 35) = 1.0 =1.0	Cumulative probability for entry QP(J,2) in the table of coordinates (card type 35) Q(J,2) ≤ Q(J,1)		Cumulative probability for entry QP(J,I) in the table of coordinates (card type 35) Q(J,I) ≤ Q(J,I-1)		Cumulative probability for entry QP(J, IMX(J)) in the table of coordinates (card type 35) Q(J, IMX(J)) = 0.
UNITS	None	None		None		
SYMBOL	Q(J,1)	Q(J,2)		Q(J,I)		Q(J, IMX(J))

Note: If IMX(J) = 0, Omit card type 34 and card type 35 for J. Input card type 34 and card type 35 for J = 1, 2, ..., 7 in the order $\underbrace{34,\ 35}_{J=1};\ \underbrace{34,\ 35}_{J=2};\ \ldots,\ \underbrace{34,\ 35}_{J=J};\ \ldots;\ \underbrace{34,\ 35}_{J=7}$

CARD TYPE 35 (J = 1)							
	WORD	1	2		I		IMX(1)
	COLUMNS	1-12	13-24				
	FORMAT	E12.5 Floating Point	E12.5 Floating Point		E12.5 Floating Point		E12.5 Floating Point
	DESCRIPTION	First entry in table of Z-coordinates (NA = 1, 2, 3, 4)	Second entry in the table of Z-coordinates (NA = 1, 2, 3, 4)		Ith entry in the table of Z-coordinates (NA = 1, 2, 3, 4)		Last entry in the table of Z-coordinates (NA = 1, 2, 3, 4)
		First entry in table of R $(=\sqrt{X^2+Y^2+Z^2})$ (NA = 5)	Second entry in table of R $(=\sqrt{X^2+Y^2+Z^2})$ (NA = 5) $QP(1,2) < QP(1,1)$		Ith entry in table of R $(=\sqrt{X^2+Y^2+Z^2})$ (NA = 5) $QP(1,I) < QP(1,I-1)$		Last entry in the table of R $(=\sqrt{X^2+Y^2+Z^2})$ (NA = 5) $QP(1,IMX(1)) \geq 0.$
	UNITS	Centimeters	Centimeters		Centimeters		Centimeters
	SYMBOL	QP(1,1)	QP(1,2)		QP(1,I)		QP(1,IMX(1))

CARD TYPE 35 (J = 2)							
	WORD	1	2		I		IMX(2)
	COLUMNS	1-12	13-24				
	FORMAT	E12.5 Floating Point	E12.5 Floating Point		E12.5 Floating Point		E12.5 Floating Point
	DESCRIPTION	First entry in the table of X-coordinates	Second entry in the table of X-coordinates		Ith entry in the table of X-coordinates		Last entry in the table of X-coordinates
	UNITS	Centimeters	Centimeters		Centimeters		Centimeters
	SYMBOL	QP(2,1)	QP(2,2)		QP(2,I)		QP(2,IMX(2))

NOTE: Omit card 34 and card 35 for J = 2 if IMX(2) = 0

CARD TYPE 35 (J = 3)							
	WORD	1	2		:		IMX(3)
	COLUMNS	1-12	13-24				
	FORMAT	E12.5 Floating Point	E12.5 Floating Point		E12.5 Floating Point		E12.5 Floating Point
	DESCRIPTION	First entry in the table of Y-coordinates	Second entry in the table of Y-coordinates		Ith entry in the table of Y-coordinates		Last entry in the table of Y-coordinates
	UNITS	Centimeters	Centimeters		Centimeters		Centimeters
	SYMBOL	QP(2, 1)	QP(3, 2)		QP(3, I)		QP(3, IMX(3))

NOTE: Omit card 34 and card 35 for J = 3 if IMX(3) = 0.

CARD TYPE 35 (J = 4)						
WORD	1	2		I		IMX(4)
COLUMNS	1-12	13-24				
FORMAT	E12.5 Floating Point	E12.5 Floating Point		E12.5 Floating Point		E12.5 Floating Point
DESCRIPTION	First entry in table of $\rho\ (= \sqrt{X^2 + Y^2})$	Second entry in table of $\rho\ (= \sqrt{X^2 + Y^2})$ QP(4, 2) < QP(4, 1)		Ith entry in table of $\rho\ (= \sqrt{X^2 + Y^2})$ QP(4, I) < QP(4, I-1)		Last entry in table of $\rho\ (= \sqrt{X^2 + Y^2})$ QP(4, IMX(4)) ≥ 0.0
UNITS	Centimeters	Centimeters		Centimetres		Centimeters
SYMBOL	QP(4, 1)	QP(4, 2)		QP(4, I)		QP(4, IMX(4))

NOTE: Omit card 34 and card 35 for J = 4 if IMX(4) = 0.

CARD TYPE 35 (J = 5)						
WORD	1	2		I		IMX(5)
COLUMNS	1-12	13-24				
FORMAT	E12.5 Floating Point	E12.5 Floating Point		E12.5 Floating Point		E12.5 Floating Point
DESCRIPTION	First entry in table of velocities (converted internally) QP(5, 1) = VSC(1) (card type 28)	Second entry in table of velocities (converted internally) QP(5, 2) > QP(5, 1) QP(5, 2) = VSC(2) (card type 28)		Ith entry in table of velocities (converted internally) QP(5, I) > QP(5, I - 1) QP(5, I) = VSC(I) (card type 28)		Last entry in table of velocities (converted internally) QP(5, IMX(5)) = VSC (IMX(5)) (card type 28)
UNITS	Electron Volts	Electron Volts		Electron Volts		Electron Volts
SYMBOL	QP(5, 1)	QP(5, 2)		QP(5, I)		QP(5, IMX(5))

CARD TYPE 35 (J = 6)							
	WORD	1	2		I		IMX(6)
	COLUMNS	1-12	13-24				
	FORMAT	E12.5 Floating Point	E12.5 Floating Point		E12.5 Floating Point		E12.5 Floating Point
	DESCRIPTION	First entry in the table of Y (direction cosine with respect to Z-axis)	Second entry in the table of Y (direction cosine with respect to Z-axis)		Ith entry in the table of Y (direction cosine with respect to Z-axis)		Last entry in the table of Y (direction cosine with respect to Z-axis)
	UNITS	None	None		None		None
	SYMBOL	QP(6, 1)	QP(6, 2)		QP(6, I)		QP(6, IMX(6))

NOTE: Omit card type 34 and card type 35 for J = 6 if IMX(6) = 0.

CARD TYPE 35 (J = 7)						
WORD	1	2		I		IMX(7)
COLUMNS	1-12	13-24				
FORMAT	E12.5 Floating Point	E12.5 Floating Point		E12.5 Floating Point		E12.5 Floating Point
DESCRIPTION	First entry in the table of β (direction cosine with respect to Y-axis)	Second entry in the table of β (direction cosine with respect to X-axis)		Ith entry in the table of β (direction cosine with respect to X-axis)		Last entry in the table of β (direction cosine with respect to X-axis)
UNITS	None	None		None		None
SYMBOL	QP(7, 1)	QP(7, 2)		QP(7, I)		QP(7, IMX(7))

NOTE: Omit card type 34 and card type 35 for J = 7 if IMX(7) = 0.

Order of Input: Card Type 34 and Card Type 35

For the definition of symbols, see Card Type 34 and Card Type 35

Card						
Card Type 34	* (Omit if IMX(1) = 0)	Q(1, 1)	Q(1, 2)	. . . Q(1, I)	. . . Q(1, IMX(1))	J = 1
Card Type 35		QP(1, 1)	QP(1, 2)	. . . QP(1, I)	. . . QP(1, IMX(1))	
Card Type 34	* (Omit if IMX(2) = 0)	Q(2, 1)	Q(2, 2)	. . . Q(2, I)	. . . Q(2, IMX(2))	J = 2
Card Type 35		QP(2, 1)	QP(2, 2)	. . . QP(2, I)	. . . QP(2, IMX(2))	
⋮						
Card Type 34	* (Omit if IMX(J) = 0)	Q(J, 1)	Q(J, 2)	. . . Q(J, I)	. . . Q(J, IMX(J))	J = J
Card Type 35		QP(J, 1)	QP(J, 2)	. . . QP(J, I)	. . . QP(J, IMX(J))	
⋮						
Card Type 34	* (Omit if IMX(7) = 0)	Q(7, 1)	Q(7, 2)	. . . Q(7, I)	. . . Q(7, IMX(7))	J = 7
Card Type 35		QP(7, 1)	QP(7, 2)	. . . QP(7, I)	. . . QP(7, IMX(7))	

*IMX(J) J = 1, 2, . . . , 6 is on card type 32
IMX(7) is on card type 33

CARD TYPE 34						
WORD	1	2		J		JMAG
COLUMNS	1-12	13-24				
FORMAT	E12.5 *Floating Point*	E12.5 *Floating Point*		E12.5 *Floating Point*		E12.5 *Floating Point*
DESCRIPTION	Flux-to-dose rate conversion for energy group 1	Flux-to-dose rate conversion for energy group 2		Flux-to-dose rate conversion for energy group J		Flux-to-dose rate conversion for energy group JMAG
UNITS	Dose Rate/Flux	Dose Rate/Flux		Dose Rate/Flux		Dose Rate/Flux
SYMBOL	FTOD(1)	FTOD(2)		FTOD(J)		FTOD(JMAG)

NOTE: Flux is defined as neutrons/cm^2-sec.

F. RESTART USING THE CENSUS TAPE

To run the next time step of a problem the following procedure is followed:

(1) The census tape of the previous time step is mounted on the initial value tape unit and is now the initial value tape.

(2) A new census tape is mounted on the census tape unit.

(3) Card Types 1 through 4 and Card Type 36 are inputed.

(4) NIV (Card Type 4) must be the number of particles on the new initial value tape as obtained from the printout of the previous time step.

Since NIV must be input for each time step, it is impossible to run successive time steps during one machine run. However, two or more problems of one time step each can be run at once by placing the data deck for each directly behind that for the preceding problem.

G. SAMPLE INPUT

The sample problem contains a list of the input as it was entered from the cards. Columns 73 to 80 indicate the card type and the card number of each card type. For example,if there were two Card Type 6 cards, they would be labeled 6-1 and 6-2 in columns 73, 74 and 75.

VII. RESULTS

A. ANSWERS GENERATED BY THE CODE

The code will generate all or part of the results listed below for a given census time. The results generated depend upon the requests made through the input. Certain results are not dependent on input requests. Certain results are either straight Monte Carlo results (SMC) or analytic estimation results (AE) depending on whether the analytic estimation routine is requested in the calculation. Some results are gotten by both SMC and AE if the analytic estimation routine is requested in the calculation. The results listed as follows are labeled SMC, SMC, and/or AE.

(1) Number of particles leaking from the system (SMC and AE).

(2) Number of neutrons leaking from the system (SMC and AE).

(3) Number of neutrons entering special tally regions (SMC or AE).

(4) Estimation of criticality (SMC).

(5) Number of neutrons scattered elastically (SMC).

(6) Number of neutrons scattered inelastically (SMC).

(7) Number of fission neutrons born versus energy (SMC).

(8) Number of particles starting life histories (SMC).

(9) Number of neutrons starting life histories (SMC).

(10) Number of particles on the census tape after census period (SMC).

(11) Number of neutrons on the census tape after census period (SMC).

(12) Neutron flux versus region and energy group (SMC or AE).

(13) Number of neutrons crossing from region ℓ to region ℓ' (SMC or AE).

(14) Number of neutrons scattered elastically versus material and energy group (SMC or AE).

(15) Number of neutrons scattered inelastically versus material and energy group (SMC or AE).

(16) Number of neutrons born in fission versus material and energy group (SMC or AE).

(17) Number of times the collision routine was entered versus material and energy group (SMC).

(18) Number of times the collision routine was entered (SMC).

(19) Number of particles that have fallen below the energy cutoff (SMC).

(20) Number of neutrons that have fallen below the energy cutoff (SMC).

(21) Dose rate versus region and energy group (SMC or AE).

(22) Total dose versus region (SMC or AE).

(23) Last random number used in the calculation.

B. SAMPLE PROBLEM

The sample problem consists of a point source of fission neutrons located at the origin, surrounded by 10 regions, all regions containing water. The geometry is described in Fig. 3.

The input cards as they were entered on tape are labeled INPUT CARDS. A printout of the input with the indirect address results are next presented and are labeled INPUT. The results of the straight Monte Carlo calculation of 10,000 particle histories are presented last and are labeled RESULTS.

This problem ran approximately 8 minutes. No splitting was requested. An examination of the fluxes for regions 3, 5, 7 and 9 show a trend that is to be expected; i.e., the flux results for regions close to the source seem to be more reliable, in that more energy groups are occupied than in regions further removed from the source. This situation could be improved (more energy groups could be occupied in regions far removed from the source, and thus would impart a larger degree of confidence in the results) by both splitting and/or requesting that analytic estimation answers be generated.

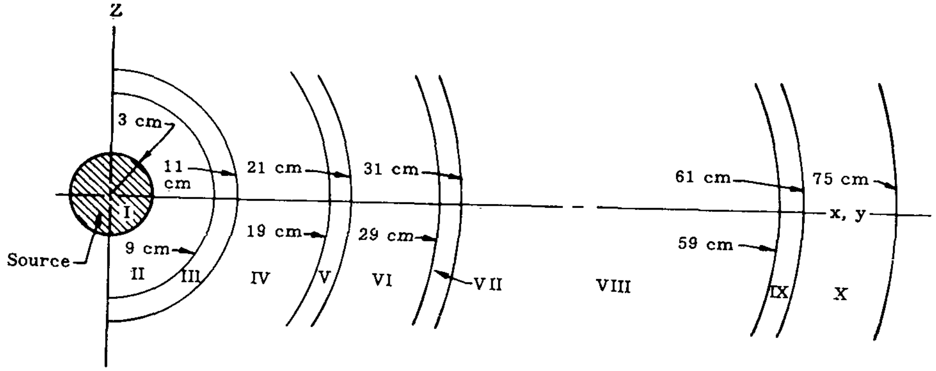


Fig. 3. Spherical Geometry of Sample Problem

INPUT

```
-- MARTIN-MARIETTA CORP - - - 1962 - - - M. J. KNIEDLER - T. M. JORDAN -

TEST PROBLEM - ATTENUATION OF FISSION NEUTRONS IN WATER
  STRAIGHT MONTE CARLO ANSWERS
  ONE PARTICLE PER SCATTER

DESIGNATION OF TAPE UNITS

    3 = M10, OUTPUT TAPE
    2 = M9, INPUT TAPE
   15 = M8, CROSS-SECTION TAPE
    5 = M7, INITIAL VALUE TAPE
   16 = M6, BREEDER TAPE
   16 = M5, FISSION TAPE
    6 = M4, CENSUS TAPE
    4 = M3, CHAIN LOADER
    7 = M2, COLLISION TAPE
   16 = M1, INELASTIC SCATTERING GAMMA TAPE
```

```
CASE NUMBER     1

THIS IS THE FIRST CASE OF A SERIES.  THE INITIAL VALUE TAPE IS GENERATED
FROM CARD INPUT. ALL DATA FOR THE NEXT CASE IS SAVED ON THE CENSUS TAPE
OF THIS CASE WITH THE EXCEPTION OF, NCT, WHICH DETERMINES WHETHER THE
                                         PROBLEM IS AN INITIAL OR
                                         RESTART PROBLEM

                                   S, THE INITIAL OCTAL RANDOM NUMBER
                                   NOPAE, THE ANALYTIC ESTIMATION OPTION
                                   NIV, THE NUMBER OF PARTICLES ON THE
                                        INITIAL VALUE TAPE

FOR THIS CASE, NCT =  0

TOTAL STORAGE ALLOCATED TO INDIRECTLY ADDRESSED ARRAYS = 18000
TOTAL STORAGE REQUIRED BY THIS PROBLEM FOR INDIRECTLY ADDRESSED ARRAYS =    494
```


MND-MC-2856

INDIRECT ADDRESSES

INDIRECT ADDRESS FOR MATERIALS

M = MATERIAL NUMBER

NTA(M) = INDIRECT ADDRESS FOR ELASTIC SCATTERING PROBABILITIES

NTB(M) = INDIRECT ADDRESS FOR INELASTIC SCATTERING PROBABILITIES

NTC(M) = INDIRECT ADDRESS FOR FISSION PROBABILITIES

NTCB(M) = INDIRECT ADDRESS FOR BREEDING PROBABILITIES

NTCC(M) = INDIRECT ADDRESS FOR NEUTRONS FROM ELASTIC AND INELASTIC SCATTER AND FISSION

M	NTA(M)	NTB(M)	NTC(M)	NTCB(M)	NTCC(M)
1	10	30	50	70	80

NTD = INDIRECT ADDRESS FOR NEUTRON YIELD OF FISSIONABLE ISOTOPES = 110

NTDAA = INDIRECT ADDRESS FOR THE FISSION SPECTRUM OF THESE ISOTOPES = 110

INDIRECT ADDRESSES FOR INELASTIC SCATTERING MATRICES

I = ISOTOPE NUMBER

NTDA(I) = INDIRECT ADDRESS FOR PROBABILITIES

I	NTDA(I)
1	110
2	165

INDIRECT ADDRESS FOR INTERPOLATING IN ARRAYS STORED BY ENERGY GROUP

N3J(J) = 3*(J - 1) USED WITH NTCC(M)

NTDB(J) = J*(J - 1)/2 USED WITH NTDA(I)

J	N3J(J)	NTDB(J)
1	0	0
2	3	1
3	6	3
4	9	6
5	12	10
6	15	15
7	18	21
8	21	28
9	24	36
10	27	45

INDIRECT ADDRESS USED IN INTERPOLATING WITHIN ARRAYS LOCATED BY NTA(M), NTB(M), AND NTC(M)

NIMAX(M) = NUMBER OF ISOTOPES IN MATERIAL M

JNIM(J,M) = J*NIMAX(M)

M	J	JNIM(J,M)
1		
	1	2
	2	4
	3	6
	4	8
	5	10
	6	12
	7	14
	8	16
	9	18
	10	20

INDIRECT ADDRESSES FOR REGION INPUT

NR = REGION NUMBER

NTE(NR) = INDIRECT ADDRESS

NR	NTE(NR)
1	220
2	231
3	248
4	265
5	282
6	299
7	316
8	333
9	350
10	367

NTF = INDIRECT ADDRESS FOR SURFACE INPUT . . . . = 384

NTG = INDIRECT ACCRESS FOR ELASTICALLY SCATTERED NEUTRONS = 464

NTH = INDIRECT ADDRESS FOR INELASTICALLY SCATTERED NEUTRONS= 464

NTI = INDIRECT ADDRESS FOR NEUTRONS FROM FISSION . . . . . . = 464

NTJ = INDIRECT ADDRESS FOR NEUTRON FLUX . . . . = 464

NTK = INDIRECT ADDRESS FOR THE NUMBER OF COLLISIONS . . . . = 504

INDIRECT ADDRESS FOR TALLIES AND CROSS-SECTIONS

NJM(I) = JMAG*(I - 1)

I	NJM(I)
1	0
2	10
3	20
4	30
5	40
6	50
7	60
8	70
9	80
10	90
11	100
12	110
13	120
14	130
15	140
16	150
17	160
18	170
19	180
20	190

10000 = NUMBER OF PARTICLES ON THE INITIAL VALUE TAPE

301643467471 = INITIAL OCTAL RANDOM NUMBER, S

1.00000E-03 = MINIMUM NEUTRON WEIGHT, DELW

0.10000E 01 MICRO-SECS. = CENSUS TIME, CT

0.20000E 02 AMU = LIGHT,HEAVY SCATTERING CUTOFF, APRIME

0.50000E-02 CM = DISTANCE INCREMENT FOR BOUNDARY CROSSING, EPSLON

0 = ANALYTIC ESTIMATION OPTION, NOPAE

0 = OPTION ON PARTICLES/FISSION, NFISF

0 = OPTION ON INELASTIC SCATTERING GAMMAS, NGAM

ANSWERS CALCULATED FOR THIS PROBLEM WILL INCLUDE

NEUTRONS ENTERING SPECIAL TALLY REGIONS 3
5
7

BOUNDARY CROSSINGS FOR 7 REGION PAIRS

FROM REGION	TO REGION
2	3
4	3
4	5
6	5
6	7
8	7
8	9

FLUX CALCULATION FOR 4 REGIONS

REGION	VOL(CUCM)
3	0.25200E 04
5	0.10100E 05
7	0.22600E 05
9	0.90500E 05

NUMBER OF UNIQUE SURFACES FOR ALL REGIONS = 10

GENERAL EQUATION OF SURFACE BY TYPE

TYPE	EQUATION
1	A*X**2 + XZERO*X + B*Y**2 + YZERO*Y + C*Z**2 + ZZERO*Z - K = 0
2	A*(X - XZERO)**2 + B*(Y -YZERO)**2 + C*(Z - ZZERO)**2 - K = 0
3	(X - XZERO)**2 + (Y - YZERO)**2 - K = 0
4	X - K = 0
5	Y - K = 0
6	Z - K = 0
7	XZERO*X + YZERO*Y + ZZERO*Z - K = 0

CONSTANTS FOR INPUT SURFACES

NUMBER	TYPE	A	B	C	K	XZERO	YZERO	ZZERO
1	2	0.10000E 01	0.10000E 01	0.10000E 01	0.90000E 01	0.	0.	0.
2	2	0.10000E 01	0.10000E 01	0.10000E 01	0.81000E 02	0.	0.	0.
3	2	0.10000E 01	0.10000E 01	0.10000E 01	0.12100E 03	0.	0.	0.
4	2	0.10000E 01	0.10000E 01	0.10000E 01	0.36100E 03	0.	0.	0.
5	2	0.10000E 01	0.10000E 01	0.10000E 01	0.44100E 03	0.	0.	0.
6	2	0.10000E 01	0.10000E 01	0.10000E 01	0.84100E 03	0.	0.	0.
7	2	0.10000E 01	0.10000E 01	0.10000E 01	0.96100E 03	0.	0.	0.
8	2	0.10000E 01	0.10000E 01	0.10000E 01	0.34810E 04	0.	0.	0.
9	2	0.10000E 01	0.10000E 01	0.10000E 01	0.37210E 04	0.	0.	0.
10	2	0.10000E 01	0.10000E 01	0.10000E 01	0.64000E 04	0.	0.	0.

NUMBER OF REGIONS = 10

DEFINITION OF SYMBOLS

NSMAX = NUMBER OF SURFACES BOUNDING THE REGION

MN = MATERIAL NUMBER OF THE REGION

NAB = AMBIGUOUS BOUNDARY TEST
= 0, NO AMBIGUOUS BOUNDARIES (FIRST SURFACE REPEATED)
= 1, YES AMBIGUOUS BOUNDARIES (FIRST 2 IN LIST)

NOR = 0, REGION IS AN INSIDE REGION
= 1, REGION IS AN OUTSIDE REGION

NPPC = NUMBER OF PARTICLES/COLLISION

AI = AMBIGUITY INDEX OF SURFACE

NOS = SURFACE NUMBER IN LIST OF ALL SURFACES

MP1 = FIRST MOST PROBABLE NEXT REGION

.

.

MP4 = FOURTH . . . .

REGION NUMBER 1

NSMAX= 1

MN = 1

NAB = 0

NOR = 0

NPPC = 1

SURFACE	AI	NOS	MP1	MP2	MP3	MP4
1	0.10000E 01	1	2	2	2	2

REGION NUMBER 2

NSMAX= 2

MN = 1

NAB = 0

NOR = 0

NPPC = 1

SURFACE	AI	NOS	MP1	MP2	MP3	MP4
1	-0.10000E 01	1	1	1	1	1
2	0.10000E 01	2	3	3	3	3

REGION NUMBER 3

NSMAX= 2

MN = 1

NAB = 0

NOR = 0

NPPC = 1

SURFACE	AI	NOS	MP1	MP2	MP3	MP4
1	-0.10000E 01	2	2	2	2	2
2	0.10000E 01	3	4	4	4	4

REGION NUMBER 4

NSMAX= 2

MN = 1

NAB = 0

NOR = 0

NPPC = 1

SURFACE	AI	NOS	MP1	MP2	MP3	MP4
1	-0.10000E 01	3	3	3	3	3
2	0.10000E 01	4	5	5	5	5

REGION NUMBER 5

NSMAX= 2

MN = 1

NAB = 0

NOR = 0

NPPC = 1

SURFACE	AI	NOS	MP1	MP2	MP3	MP4
1	-0.10000E 01	4	4	4	4	4
2	0.10000E 01	5	6	6	6	6

REGION NUMBER 6

NSMAX= 2

MN = 1

NAB = 0

NOR = 0

NPPC = 1

SURFACE	AI	NOS	MP1	MP2	MP3	MP4
1	-0.10000E 01	5	5	5	5	5
2	0.10000E 01	6	7	7	7	7

REGION NUMBER 7

NSMAX= 2

MN = 1

NAB = 0

NOR = 0

NPPC = 1

SURFACE	AI	NOS	MP1	MP2	MP3	MP4
1	-0.10000E 01	6	6	6	6	6
2	0.10000E 01	7	8	8	8	8

REGION NUMBER 8

NSMAX= 2

MN = 1

NAB = 0

NOR = 0

NPPC = 1

SURFACE	AI	NOS	MP1	MP2	MP3	MP4
1	-0.10000E 01	7	7	7	7	7
2	0.10000E 01	8	9	9	9	9

```
REGION NUMBER   9
      NSMAX=  2
      MN    =  1
      NAB   =  0
      NOR   =  0
      NPPC  =  1
        SURFACE        AI          NOS   MP1   MP2   MP3   MP4
          1       -0.10000E 01      8     8     8     8     8
          2        0.10000E 01      9    10    10    10    10

REGION NUMBER  10
      NSMAX=  2
      MN    =  1
      NAB   =  0
      NOR   =  1
      NPPC  =  1
        SURFACE        AI          NOS   MP1   MP2   MP3   MP4
          1       -0.10000E 01      9     9     9     9     9
          2        0.10000E 01     10     0     0     0     0
```



```
TOTAL NUMBER OF MATERIALS =   1

MATERIAL NUMBER  1
THIS MATERIAL CONTAINS  2 ISOTOPES
NBREED =  0

IDENTIFICATION OF ISOTOPES IN THIS MATERIAL   NI   K(NI)
                                               1     1
                                               2     2

TOTAL NUMBER OF ISOTOPES =   2
NO. OF FISSIONABLE ISOTOPES =   0

LTEST =    0 THE REQUIRED PROBABILITIES AND CROSS-SECTIONS ARE READ AND
              CALCULATED FROM CARD INPUT AND SAVED ON THE CROSS-SECTION
              TAPE, M8,FOR INPUT TO ANOTHER PROBLEM.
```

ISOTOPE NUMBER 1 ATOMIC WEIGHT = 0.10000E 01 AMU

INELASTIC SCATTERING MATRIX

J	INELASTIC SCATTERING PROBABILITIES				
1	0.				
2	0.	0.			
3	0.	0.	0.		
4	0.	0.	0.	0.	
5	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.
	0.				
7	0.	0.	0.	0.	0.
	0.	0.			
8	0.	0.	0.	0.	0.
	0.	0.	0.		
9	0.	0.	0.	0.	0.
	0.	0.	0.	0.	
10	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.

ISOTOPE NUMBER 2 ATOMIC WEIGHT = 0.16000E 02 AMU

INELASTIC SCATTERING MATRIX

J	INELASTIC SCATTERING PROBABILITIES				
1	0.				
2	0.	0.			
3	0.	0.	0.		
4	0.	0.	0.	0.	
5	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.
	0.				
7	0.	0.	0.	0.	0.
	0.	0.			
8	0.	0.	0.	0.	0.
	0.	0.	0.		
9	0.	0.	0.	0.	0.
	0.	0.	0.	0.	
10	0.	0.	0.	0.	0.
	0.	0.	0.	0.	0.

INPUT FOR PROBABILITY CALCULATIONS

J = ENERGY GROUP

SEL = ELASTIC SCATTERING CROSS-SECTION

SIN = INELASTIC SCATTERING CROSS-SECTION

SFIS = FISSION CROSS-SECTION

SCAP = CAPTURE CROSS-SECTION

ALL CROSS-SECTIONS HAVE UNITS OF BARNS

MATERIAL 1 DENSITY 0.10000E 01 GM/CUCM

ISOTOPE	WEIGHT FRACTION
1	0.11110E-00
2	0.88880E 00

ISOTOPE 1 J	SEL	SIN	SFIS	SCAP
1	0.87800E 00	0.	0.	0.
2	0.10600E 01	0.	0.	0.
3	0.13100E 01	0.	0.	0.
4	0.15600E 01	0.	0.	0.
5	0.18000E 01	0.	0.	0.
6	0.21100E 01	0.	0.	0.
7	0.26300E 01	0.	0.	0.
8	0.35600E 01	0.	0.	0.
9	0.53000E 01	0.	0.	0.
10	0.88000E 01	0.	0.	0.

ISOTOPE 2 J	SEL	SIN	SFIS	SCAP
1	0.30000E-00	0.	0.	0.90000E 00
2	0.45000E-00	0.	0.	0.66000E 00
3	0.86000E 00	0.	0.	0.24000E-00
4	0.11000E 01	0.	0.	0.15000E-00
5	0.19000E 01	0.	0.	0.12000E-00
6	0.28000E 01	0.	0.	0.50000E-01
7	0.18300E 01	0.	0.	0.
8	0.18300E 01	0.	0.	0.
9	0.18300E 01	0.	0.	0.
10	0.18300E 01	0.	0.	0.

CALCULATED PROBABILITIES

NI = ISOTOPE NUMBER (OF THE MATERIAL)
PSE = PROBABILITY FOR ELASTIC SCATTERING
PSI = PROBABILITY FOR IN-ELASTIC SCATTERING
PSF = PROBABILITY FOR FISSION
PBREED = PROBABILITY FOR BREEDING (FIRST ISOTOPE ONLY, ONLY IF NBREED = 1)
PS1 = NEUTRONS PER ELASTIC SCATTER
PS2 = NEUTRONS PER INELASTIC SCATTER
PS3 = NEUTRONS PER FISSION
XSECT = NEUTRON REMOVAL CROSS-SECTION (1/CM)

PROBABILITIES FOR NEUTRON INTERACTIONS - MATERIAL NUMBER 1

```
ENERGY
GROUP
   1     NI          PSE            PSI            PSF
          1     0.59405E 00  0.69553E 00  0.69553E 00
          2     0.69553E 00  0.69553E 00  0.69553E 00
            XSECT  =  0.98901E-01
            PS1    =  0.69553E 00
            PS2    =  0.
            PS3    =  0.
   2     NI          PSE            PSI            PSF
          1     0.65635E 00  0.79567E 00  0.79567E 00
          2     0.79567E 00  0.79567E 00  0.79567E 00
            XSECT  =  0.10807E-00
            PS1    =  0.79567E 00
            PS2    =  0.
            PS3    =  0.
   3     NI          PSE            PSI            PSF
          1     0.70430E 00  0.93548E 00  0.93548E 00
          2     0.93548E 00  0.93548E 00  0.93548E 00
            XSECT  =  0.12446E-00
            PS1    =  0.93548E 00
            PS2    =  0.
            PS3    =  0.
   4     NI          PSE            PSI            PSF
          1     0.71396E 00  0.96568E 00  0.96568E 00
          2     0.96568E 00  0.96568E 00  0.96568E 00
            XSECT  =  0.14621E-00
            PS1    =  0.96568E 00
            PS2    =  0.
            PS3    =  0.
```

```
 5   NI        PSE          PSI          PSF
      1   0.64057E 00  0.97865E 00  0.97865E 00
      2   0.97865E 00  0.97865E 00  0.97865E 00

       XSECT =  0.18803E-00
       PS1   =  0.97865E 00
       PS2   =  0.
       PS3   =  0.
 6   NI        PSE          PSI          PSF
      1   0.59689E 00  0.99293E 00  0.99293E 00
      2   0.99293E 00  0.99293E 00  0.99293E 00

       XSECT =  0.23655E-00
       PS1   =  0.99293E 00
       PS2   =  0.
       PS3   =  0.
 7   NI        PSE          PSI          PSF
      1   0.74189E 00  1.00000E 00  1.00000E 00
      2   1.00000E 00  1.00000E 00  1.00000E 00

       XSECT =  0.23722E-00
       PS1   =  1.00000E 00
       PS2   =  0.
       PS3   =  0.
 8   NI        PSE          PSI          PSF
      1   0.73553E 00  1.00000E 00  1.00000E 00
      2   1.00000E 00  1.00000E 00  1.00000E 00

       XSECT =  0.29945E-00
       PS1   =  1.00000E 00
       PS2   =  0.
       PS3   =  0.
 9   NI        PSE          PSI          PSF
      1   0.85278E 00  1.00000E 00  1.00000E 00
      2   1.00000E 00  1.00000E 00  1.00000E 00

       XSECT =  0.41588E-00
       PS1   =  1.00000E 00
       PS2   =  0.
       PS3   =  0.
10   NI        PSE          PSI          PSF
      1   0.90582E 00  1.00000E 00  1.00000E 00
      2   1.00000E 00  1.00000E 00  1.00000E 00

       XSECT =  0.65008E 00
       PS1   =  1.00000E 00
       PS2   =  0.
       PS3   =  0.
```


ENERGY AND VELOCITY VERSUS ENERGY LEVEL

ENERGY LEVEL	ENERGY (ELECTRON-VOLTS)	VELOCITY (CM/MICRO-SEC)
1	0.50000E 06	0.97521E 03
2	0.10000E 07	0.13792E 04
3	0.15000E 07	0.16891E 04
4	0.20000E 07	0.19504E 04
5	0.25000E 07	0.21806E 04
6	0.30000E 07	0.23888E 04
7	0.40000E 07	0.27583E 04
8	0.50000E 07	0.30839E 04
9	0.70000E 07	0.36489E 04
10	0.90000E 07	0.41375E 04
11	0.12000E 08	0.47775E 04

PARTICLE GENERATOR INPUT

1 CASES

CASE NUMBER 1

NPIV = 10000 = TOTAL NUMBER OF PARTICLES GENERATED AT THE END OF THIS CASE

NA = 5 DETERMINES SELECTION OF COORDINATES

NE = 1 DETERMINES SELECTION OF DIRECTION COSINES

NH = 1 DETERMINES SELECTION OF TIME

NRIN = 1 = REGION IN WHICH PARTICLE IS BORN

TIN = 0.10000E 04 = INPUT TIME

WIN = 0.10000E 01 = WEIGHT OF PARTICLE

NTRA = -0 OPTION ON COORDINATE TRANSLATION

TRANSLATION COORDINATES

-0. = XZRO

-0. = YZRO

-0. = ZZRO

TABLE NUMBER 1 - 7 ENTRIES

Q-TABLE PROBABILITY	QP-TABLE COORDINATE
0.10000E 01	0.30000E 01
0.57810E 00	0.25000E 01
0.29600E-00	0.20000E 01
0.12480E-00	0.15000E 01
0.37000E-01	0.10000E 01
0.46000E-02	0.50000E 00
0.	0.

TABLE NUMBER 5 - 11 ENTRIES

Q-TABLE PROBABILITY	QP-TABLE COORDINATE
0.10000E 01	0.97521E 03
0.82500E 00	0.13792E 04
0.63200E 00	0.16891E 04
0.49300E-00	0.19504E 04
0.34640E-00	0.21806E 04
0.25000E-00	0.23888E 04
0.12630E-00	0.27583E 04
0.61700E-01	0.30839E 04
0.13720E-01	0.36489E 04
0.28550E-02	0.41375E 04
0.	0.47775E 04

INPUT CARDS

* DATA						
3	2	15	5	16		161
6	4	7	16			2
TEST PROBLEM - ATTENUATION OF FISSION NEUTRONS IN WATER						3-1
STRAIGHT MONTE CARLO ANSWERS						3-2
ONE PARTICLE PER SCATTER						3-3
0	0	10000301643467471				4
1	2	0	10	10		105
2						6
1	2	2	2	2		27-1
2	2	2	2			7-2
7	0	4	0	0		8
1.+0	1.-3	20.00000+0	5.00000-3			9
3	5	7				10
2	3	4	3	4		511-1
6	5	6	7	8		711-2
8	9					11-3
3	2.52+3	5	1.01+4	7	2.26+4	13-1
9	9.05+4					13-2
2	1.00000+0	1.00000+0	1.00000+0	9.30000+0		14-1
0.00000+0	0.00000+0	0.00000+0				15-2
2	1.00000+0	1.00000+0	1.00000+0	8.10000+1		14-2
0.00000+0	0.00000+0	0.00000+0				15-2
2	1.00000+0	1.00000+0	1.00000+0	1.21000+2		14-3
0.00000+0	0.00000+0	0.00000+0				15-3
2	1.00000+0	1.00000+0	1.00000+0	3.61000+2		14-4
0.00000+0	0.00000+0	0.00000+0				15-4
2	1.00000+0	1.00000+0	1.00000+0	4.41000+2		14-5
0.00000+0	0.00000+0	0.00000+0				15-5
2	1.00000+0	1.00000+0	1.00000+0	8.41000+2		14-6
0.00000+0	0.00000+0	0.00000+0				15-6
2	1.00000+0	1.00000+0	1.00000+0	9.61000+2		14-7
0.00000+0	0.00000+0	0.00000+0				15-7
2	1.00000+0	1.00000+0	1.00000+0	3.48100+3		14-8
0.00000+0	0.00000+0	0.00000+0				15-8
2	1.00000+0	1.00000+0	1.00000+0	3.72100+3		14-9
0.00000+0	0.00000+0	0.00000+0				15-9
2	1.00000+0	1.00000+0	1.00000+0	5.40000+3		14-10
0.00000+0	0.00000+0	0.00000+0				15-10
1	0	0	1			16-1
1.00000+0	1	2	2	2		217-1-1

1	0	0	1		16-2
-1.	1	1	1	1	117-2-1
1.	2	3	3	3	317-2-2
1	0	0	1		16-3
-1.	2	2	2	2	217-3-1
1.	3	4	4	4	417-3-2
1	0	0	1		16-4
-1.	3	3	3	3	317-4-1
1.	4	5	5	5	517-4-2
1	0	0	1		16-5
-1.	4	4	4	4	417-5-1
1.	5	6	6	6	617-5-2
1	0	0	1		16-6
-1.	5	5	5	5	517-6-1
1.	6	7	7	7	717-6-2
1	0	0	1		16-7
-1.	6	5	6	6	617-7-1
1.	7	8	8	8	817-7-2
1	0	0	1		16-8
-1.	7	7	7	7	717-8-1
1.	8	9	9	9	917-8-2

1	0	0	1		16-9
-1.	8	8	8	8	817-9-1
1.	9	10	10	10	1017-9-2
1	0	1	1		16-10
-1.	9	9	9	9	917-10-1
1.	10	0	0	0	017-10-2
0					18
1	2				19
1.00000+0	16.00000+0				20
0					21
0.00000+0					22-1-1
0.00000+0	0.00000+0				22-1-2
0.00000+0	0.00000+0	0.00000+0			22-1-3
0.00000+0	0.00000+0	0.00000+0	0.00000+0		22-1-4
0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+0	22-1-5
0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+022-1-6
0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+022-1-7-1
0.00000+0					22-1-7-2
0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+022-1-8-1
0.00000+0	0.00000+0				22-1-8-2
0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+022-1-9-1
0.00000+0	0.00000+0	0.00000+0			22-1-9-2
0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+022-1-10-
0.00000+0	0.00000+0	0.00000+0	0.00000+0		22-1-10-

0.00000+0					
0.00000+0	0.00000+0				22-2-1
0.00000+0	0.00000+0	0.00000+0			22-2-2
0.00000+0	0.00000+0	0.00000+0	0.00000+0		22-2-3
0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+0	22-2-4
0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+0	22-2-5
0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+022-2-6
0.00000+0					0.00000+022-2-7-1
0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+0	22-2-7-2
0.00000+0	0.00000+0				0.00000+022-2-8-1
0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+0	22-2-8-2
0.00000+0	0.00000+0	0.00000+0			0.00000+022-2-9-1
0.00000+0	0.00000+0	0.00000+0	0.00000+0	0.00000+0	22-2-9-2
0.00000+0	0.00000+0	0.00000+0	0.00000+0		0.00000+022-2-10-
1.00000+0					22-2-10-
0.11110+0	0.88880+0				25
0.87800+0	0.00000+0	0.00000+0	0.00000+0		26
1.06000+0	0.00000+0	0.00000+0	0.00000+0		27-1-1
1.31000+0	0.00000+0	0.00000+0	0.00000+0		27-2-1
1.56000+0	0.00000+0	0.00000+0	0.00000+0		27-3-1
1.80000+0	0.00000+0	0.00000+0	0.00000+0		27-4-1
2.11000+0	0.00000+0	0.00000+0	0.00000+0		27-5-1
2.63000+0	0.00000+0	0.00000+0	0.00000+0		27-6-1
3.56000+0	0.00000+0	0.00000+0	0.00000+0		27-7-1
5.30000+0	0.00000+0	0.00000+0	0.00000+0		27-8-1
8.80000+0	0.00000+0	0.00000+0	0.00000+0		27-9-1
0.30000+0	0.00000+0	0.00000+0	0.90000+0		27-10-1
0.45000+0	0.00000+0	0.00000+0	0.66000+0		27-1-2
0.86000+0	0.00000+0	0.00000+0	0.24000+0		27-2-2
1.10000+0	0.00000+0	0.00000+0	0.15000+0		27-3-2
1.90000+0	0.00000+0	0.00000+0	0.12000+0		27-4-2
2.80000+0	0.00000+0	0.00000+0	0.05000+0		27-5-2
1.83000+0	0.00000+0	0.00000+0	0.05000+0		27-6-2
1.83000+0	0.00000+0	0.00000+0	0.00000+0		27-7-2
1.83000+0	0.00000+0	0.00000+0	0.00000+0		27-8-2
1.83000+0	0.00000+0	0.00000+0	0.00000+0		27-9-2
					27-10-2
.5+6	1.+5	1.5+6	2.+6	2.5+6	3.+628-1
4.+6	5.+6	7.+6	9.+6	12.+6	28-2
1					29

5	1	1	1	10000	30
1.+3	1.00000+0				31
7	0	0	0	11	032
0					33
1.	.5781	.296	.1248	.037	.004634-1-1
0.					34-1-2
3.	2.5	2.	1.5	1.	.535-1-1
0.					35-1-2
1.	.825	.632	.493	.3464	.25034-5-1
.1263	.0617	.01372	.002855	0.	34-5-2
.5+6	1.+6	1.5+6	2.+6	2.5+6	3.+635-5-1
4.+6	5.+6	7.+6	9.+6	12.+6	35-5-2
9.3-9	1.26-8	1.44-8	1.51-8	1.63-8	2.01-836-1
2.01-8	2.01-8	2.01-8	2.01-8		36-2

COORDINATES OF FIRST 50 PARTICLES

X	Y	Z	ALPHA	BETA	GAMMA
-0.17903E 01	0.61813E 00	-0.12320E 01	-0.74593E 00	-0.45784E-00	0.48371E-00
-0.18536E 01	-0.20752E 01	-0.80542E 00	0.17685E-00	0.81890E 00	-0.54602E 00
-0.18245E 01	-0.79909E-01	0.12183E 01	0.37351E-00	-0.69964E 00	0.60910E 00
-0.42708E-00	-0.21931E 01	-0.40764E-00	-0.53196E 00	-0.26830E-00	0.80314E 00
0.22571E 01	-0.14191E 01	0.18723E-00	-0.89256E 00	0.40043E-00	0.20736E-00
-0.93773E 00	0.10995E 01	-0.51056E 00	-0.31088E-00	-0.91543E 00	0.25562E-00
0.11027E-01	0.14473E 01	0.42762E-00	0.80221E 00	-0.58141E 00	0.13571E-00
-0.13586E 01	-0.16105E 01	0.36808E-00	0.21021E-00	-0.95398E 00	0.21388E-00
-0.85561E 00	-0.54607E 00	0.19211E 01	-0.10025E-00	0.75168E 00	-0.65186E 00
-0.14223E 01	0.65046E 00	0.28650E-00	0.97027E 00	-0.86021E-01	0.22624E-00

W	T	V	J	NR
0.10000E 01	0.	0.10383E 04	1	1
0.10000E 01	0.	0.46411E 04	10	1
0.10000E 01	0.	0.12191E 04	1	1
0.10000E 01	0.	0.34856E 04	8	1
0.10000E 01	0.	0.22649E 04	5	1
0.10000E 01	0.	0.33918E 04	8	1
0.10000E 01	0.	0.16276E 04	2	1
0.10000E 01	0.	0.22788E 04	5	1
0.10000E 01	0.	0.15430E 04	2	1
0.10000E 01	0.	0.13437E 04	1	1

X	Y	Z	ALPHA	BETA	GAMMA
-0.40483E-00	0.28876E 01	0.81599E-01	-0.19128E-00	-0.97780E 00	-0.85586E-01
-0.11872E 01	-0.75446E 00	0.24498E 01	-0.89838E 00	-0.35849E-00	0.25379E-00
-0.25375E-00	0.45494E-00	0.28601E 01	-0.77627E 00	0.17671E-00	0.60513E 00
-0.25013E 01	-0.53030E-01	-0.37847E-00	-0.33232E-00	-0.74425E 00	-0.57936E 00
0.11206E 01	-0.10797E 01	0.10513E 01	-0.49897E-00	-0.77783E 00	-0.36210E-00
0.94645E 00	-0.17907E 01	-0.17311E 01	-0.84060E 00	-0.23954E-00	-0.48581E-00
-0.14548E-00	0.11401E 01	-0.16579E 01	0.13635E-00	-0.78862E-01	-0.98752E 00
-0.24091E 01	0.16299E 01	-0.83380E-01	-0.86102E 00	0.40335E-00	0.30978E-00
0.80516E 00	0.51853E 00	-0.12721E 01	0.50425E 00	-0.23542E-00	0.63085E 00
0.11292E 01	-0.85893E 00	-0.14007E 01	-0.41545E-00	-0.88271E 00	-0.21960E-00

W	T	V	J	NR
0.10000E 01	0.	0.16706E 04	2	1
0.10000E 01	0.	0.21426E 04	4	1
0.10000E 01	0.	0.11917E 04	1	1
0.10000E 01	0.	0.17151E 04	3	1
0.10000E 01	0.	0.14400E 04	2	1
0.10000E 01	0.	0.18880E 04	3	1
0.10000E 01	0.	0.14875E 04	2	1
0.10000E 01	0.	0.16562E 04	2	1
0.10000E 01	0.	0.26777E 04	6	1
0.10000E 01	0.	0.14797E 04	2	1

```
     X            Y            Z          ALPHA         BETA         GAMMA
-0.42033E-00 0.71209E 00 0.48583E-00 0.86182E 00 0.10805E-00 0.49557E-00
-0.15559E 01 0.19072E 01-0.60148E 00 0.63298E 00-0.74590E 00 0.20731E-00
 0.32904E-00-0.16813E 01-0.23974E 01-0.31325E-01-0.12222E-00-0.99201E 00
-0.40859E-00 0.75634E 00-0.12328E-00 0.90600E 00-0.41052E-00 0.10311E-00
-0.19864E 01-0.64763E 00-0.80765E 00-0.95158E 00 0.30739E-00-0.26312E-02
-0.10288E 01-0.13566E 01-0.12069E 01 0.35039E-00 0.72372E 00-0.59452E 00
-0.28756E-00-0.46466E-00-0.27614E 01 0.64719E 00 0.18152E-00 0.74040E 00
-0.23734E 01 0.96562E 00 0.14529E-00-0.15915E-00 0.95095E 00-0.26526E-00
-0.34793E-00-0.20297E 01-0.21262E 01 0.85030E 00-0.52597E 00 0.18613E-01
 0.20385E 01 0.85316E 00-0.11032E 01 0.67542E 00-0.15022E-00-0.72197E 00
```

```
     W          T          V           J        NR
0.10000E 01 0.        0.19678E 04      4         1
0.10000E 01 0.        0.22780E 04      5         1
0.10000E 01 0.        0.27231E 04      6         1
0.10000E 01 0.        0.18892E 04      3         1
0.10000E 01 0.        0.29066E 04      7         1
0.10000E 01 0.        0.27600E 04      7         1
0.10000E 01 0.        0.10424E 04      1         1
0.10000E 01 0.        0.23752E 04      5         1
0.10000E 01 0.        0.26459E 04      6         1
0.10000E 01 0.        0.19414E 04      3         1
```

```
     X            Y            Z          ALPHA         BETA         GAMMA
0.14500E 01 0.10778E 01-0.86044E 00 0.40563E-00 0.54779E 00-0.73171E 00
0.11394E 01 0.33793E-00-0.17667E 01-0.84308E 00 0.13836E-00 0.51968E 00
0.42962E-00 0.90635E 00 0.11837E 01 0.47955E-00 0.19273E-00-0.85609E 00
0.16657E 01 0.15706E 01 0.18569E 01-0.62474E 00 0.47354E-00-0.62086E 00
0.23221E 01 0.16450E 01-0.44822E-00-0.49724E-00-0.84846E 00 0.18131E-00
0.22000E 01-0.11849E 01-0.35138E-00-0.39696E-00 0.46761E-00 0.78979E 00
-0.76851E 00 0.31574E-00-0.26297E 01 0.43139E-00 0.47247E-00 0.76855E 00
-0.44724E-00-0.59334E 00 0.68059E-01 0.93956E 00 0.34198E-00 0.16624E-01
0.14633E-00-0.66663E 00 0.18813E 01-0.22026E-00-0.17983E-00 0.95872E 00
-0.14969E 01 0.16559E 01 0.10081E 01 0.94986E 00-0.19454E-00 0.24480E-00
```

```
     W          T          V           J        NR
0.10000E 01 0.        0.24824E 04      6         1
0.10000E 01 0.        0.23347E 04      5         1
0.10000E 01 0.        0.13127E 04      1         1
0.10000E 01 0.        0.21090E 04      4         1
0.10000E 01 0.        0.20237E 04      4         1
0.10000E 01 0.        0.17736E 04      3         1
0.10000E 01 0.        0.15538E 04      2         1
0.10000E 01 0.        0.25651E 04      6         1
0.10000E 01 0.        0.31299E 04      8         1
0.10000E 01 0.        0.15896E 04      2         1
```



```
     X            Y            Z          ALPHA         BETA         GAMMA
-0.20085E 01 0.78763E 00-0.15876E 01 0.34595E-01-0.87131E 00 0.48950E-00
 0.69463E 00 0.20846E-00-0.23549E 01 0.99498E 00-0.18734E-01-0.98315E-01
-0.10687E 01 0.21631E 01-0.15662E 01 0.94566E 00-0.12222E-00-0.30130E-00
-0.51777E 00-0.38720E-00 0.89955E 00 0.66500E 00-0.48911E-00 0.56441E 00
 0.12160E 01 0.35425E-00-0.97164E-01 0.71099E 00-0.47619E-01 0.70158E 00
-0.10985E 01 0.50079E-01-0.71729E 00-0.52843E 00 0.76488E 00 0.36840E-00
 0.13186E 01-0.11207E 01-0.14827E-00 0.60669E 00 0.71507E 00-0.34728E-00
-0.14879E 01-0.14471E 01 0.16469E 01-0.72736E 00-0.24256E-00-0.64196E 00
-0.18999E 01-0.97527E 00-0.49118E-00 0.45803E-00 0.80966E 00 0.36696E-00
 0.10779E 01-0.13471E 01-0.21218E 01 0.52951E 00 0.45156E-00 0.71814E 00
```

```
     W          T          V           J        NR
0.10000E 01 0.        0.25817E 04      6         1
```

```
0.10000E 01 0.        0.18962E 04      3         1
0.10000E 01 0.        0.20099E 04      4         1
0.10000E 01 0.        0.14637E 04      2         1
0.10000E 01 0.        0.10792E 04      1         1
0.10000E 01 0.        0.14375E 04      2         1
0.10000E 01 0.        0.29139E 04      7         1
0.10000E 01 0.        0.99239E 03      1         1
0.10000E 01 0.        0.19068E 04      3         1
0.10000E 01 0.        0.30401E 04      7         1
```

RESULTS

```
TOTAL NUMBER OF PARTICLES REJECTED IN RFIND AND SFIND          =            0
TOTAL NUMBER OF NEUTRONS REJECTED IN RFIND AND SFIND           =  0.
TOTAL NUMBER OF PARTICLES REJECTED IN SPLT                     =            0
TOTAL NUMBER OF NEUTRONS REJECTED IN SPLT                      =  0.
TOTAL NUMBER OF PARTICLES KILLED BY RUSSIAN ROULETTE           =            0

TOTAL NUMBER OF NEUTRONS KILLED BY RUSSIAN ROULETTE            =  0.

TOTAL NUMBER OF RECORDS OF 20 GAMMAS EACH ON TAPE M1           =            0

NUMBER OF UNIQUE GAMMAS IN THE LAST RECORD                     =            0


STRAIGHT MONTE CARLO RESULTS

TOTAL NUMBER OF PARTICLES AT THE START OF THE CENSUS PERIOD =           10000

TOTAL NUMBER OF PARTICLES AT THE END OF THE CENSUS PERIOD      =            0

TOTAL NUMBER OF NEUTRONS AT THE START OF THE CENSUS PERIOD     =  0.10000E 05

TOTAL NUMBER OF NEUTRONS AT THE END OF THE CENSUS PERIOD       =  0.

TOTAL NUMBER OF NEUTRONS SCATTERED ELASTICALLY                 =  0.21663E 05

TOTAL NUMBER OF NEUTRONS SCATTERED IN-ELASTICALLY              =  0.

TOTAL NUMBER OF NEUTRONS CAUSING FISSION                       =  0.

TOTAL NUMBER OF NEUTRONS BORN IN FISSION                       =  0.

TOTAL NUMBER OF NEUTRONS ABSORBED                              =  0.36160E 04

TOTAL NUMBER OF NEUTRONS CAUSING BREEDING                      =  0.

TOTAL NUMBER OF PARTICLES BELOW ENERGY CUTOFF                  =         6227

TOTAL NUMBER OF NEUTRONS BELOW ENERGY CUTOFF                   =  0.62270E 04

TOTAL NUMBER OF TIMES THE COLLISION ROUTINE WAS ENTERED        =        25279
```

ESTIMATION OF K-EFFECTIVE
FNT = NEUTRONS BORN IN FISSION
TW = NEUTRONS STARTING OUT
ABNTS = NEUTRONS ABSORBED
XLEAK = NEUTRONS THAT ESCAPED
WNNOCT = NEUTRONS AT END
FSNTS = NEUTRONS CAUSING FISSION
ENGCUT = NEUTRONS BELOW ENERGY CUTOFF
WVELCT = NEUTRONS REJECTED IN SPLT

WREJCT = NEUTRONS REJECTED IN SFIND AND RFIND
RRCUT = NEUTRONS KILLED BY RUSSIAN ROULETTE
ABSRB = FSNTS + ABNTS + XLEAK + ENGCUT + WVELCT + WREJCT + RRCUT

WNNOCT/TW = 0.

FNT/ABSRB = 0.

NUMBER OF FISSION NEUTRONS BORN VERSUS INCIDENT NEUTRON ENERGY

ENERGY GROUP	NEUTRONS BORN
1	0.
2	0.
3	0.
4	0.
5	0.
6	0.
7	0.
8	0.
9	0.
10	0.

NUMBER OF FISSION NEUTRONS BORN VERSUS ENERGY AT BIRTH

ENERGY GROUP	NEUTRONS BORN
1	0.
2	0.
3	0.
4	0.
5	0.
6	0.
7	0.
8	0.
9	0.
10	0.

TOTAL NUMBER OF FISSIONABLE ATOMS FORMED FROM ABSORBTION VERSUS REGION

REGION	ATOMS FORMED

TOTAL NUMBER OF NEUTRONS GOING FROM REGION L TO REGION LP

REGION L	REGION LP	NEUTRONS
2	3	0.66820E 04
4	3	0.16600E 03
4	5	0.35030E 04
6	5	0.78000E 02
6	7	0.17260E 04
8	7	0.38000E 02
8	9	0.18100E 03

TOTAL NUMBER OF NEUTRONS ENTERING SPECIAL TALLY REGIONS

REGION	NEUTRONS
3	0.68460E 04
5	0.35610E 04
7	0.17640E 04

FLUX TO DOSE RATE CONVERSION FACTOR VERSUS ENERGY GROUP

ENERGY GROUP	CONVERSION FACTOR
1	0.93000E-08
2	0.12600E-07
3	0.14400E-07
4	0.15100E-07
5	0.16300E-07
6	0.20100E-07
7	0.20100E-07
8	0.20100E-07
9	0.20100E-07
10	0.20100E-07

NEUTRON FLUX AND DOSE RATE VERSUS ENERGY GROUP FOR REGION 3

ENERGY GROUP	NEUTRONS PER SQCM-SEC	DOSE RATE
1	0.37070E 06	0.34475E-02
2	0.33539E 06	0.42259E-02
3	0.25833E 06	0.37199E-02
4	0.21902E 06	0.33072E-02
5	0.12592E 06	0.20525E-02
6	0.12369E 06	0.24862E-02
7	0.45702E 05	0.91862E-03
8	0.19722E 05	0.39641E-03
9	0.29246E 04	0.58784E-04
10	0.43976E 02	0.88392E-06
TOTAL		0.20614E-01

NEUTRON FLUX AND DOSE RATE VERSUS ENERGY GROUP FOR REGION 5

ENERGY GROUP	NEUTRONS PER SQCM-SEC	DOSE RATE
1	0.71509E 05	0.66504E-03
2	0.51943E 05	0.65448E-03
3	0.35584E 05	0.51240E-03
4	0.17019E 05	0.25699E-03
5	0.92005E 04	0.14997E-03
6	0.42052E 04	0.84525E-04
7	0.12292E 04	0.24706E-04
8	0.62906E 03	0.12644E-04
9	0.	0.
10	0.	0.
TOTAL		0.23608E-02

NEUTRON FLUX AND DOSE RATE VERSUS ENERGY GROUP FOR REGION 7

ENERGY GROUP	NEUTRONS PER SQCM-SEC	DOSE RATE
1	0.18947E 05	0.17620E-03
2	0.11316E 05	0.14258E-03
3	0.53472E 04	0.76999E-04
4	0.22518E 04	0.34003E-04
5	0.10126E 04	0.16506E-04
6	0.17669E 03	0.35515E-05
7	0.83136E 02	0.16710E-05
8	0.	0.
9	0.	0.
10	0.	0.
TOTAL		0.45151E-03

NEUTRON FLUX AND DOSE RATE VERSUS ENERGY GROUP FOR REGION 9

ENERGY GROUP	NEUTRONS PER SQCM-SEC	DOSE RATE
1	0.62013E 03	0.57672E-05
2	0.21676E 03	0.27312E-05
3	0.46158E 02	0.66487E-06
4	0.24023E 02	0.36275E-06
5	0.22263E 02	0.36289E-06
6	0.	0.
7	0.	0.
8	0.	0.
9	0.	0.
10	0.	0.
TOTAL		0.98889E-05

TOTAL LEAKAGE FROM THE SYSTEM

PARTICLES MONTE CARLO	NEUTRONS MONTE CARLO
157	0.15700E 03

314024013145 = FINAL OCTAL RANDOM NUMBER, S

1242 LINES OUTPUT THIS JOB.

DATE	BEGIN JOB	END JOB	LINES
620728	230738	231533	1242

VIII. MAIN PROGRAMS AND SUBROUTINES IN EACH CHAIN

The flow diagrams in Appendix A provide a detailed description of the code. The function of the main program in each chain and the subroutines controlled by each chain are given here.

A. CHAIN 1

1. P-PREP--Main Program of Chain One

P-PREP reads input from input tape; writes input on output tape; generates the coordinates of the particles (Chapter IV) for the desired regions (if requested); calculates the probabilities of breeding, scattering (inelastically and elastically), fission, and absorption for materials and isotopes in each material (Chapter V); and calculates the storage requirements.

2. RANNO--Subroutine of Chain One

RANNO generates random numbers.

3. TAPEID

TAPEID reads logical designation of tape units.

B. CHAIN 2

1. MAIN--Main Program of Chain Two

MAIN is the heart of the calculation, since the actual particle histories are controlled by the MAIN program (Chapter III).

2. SFIND--Subroutine of Chain Two

SFIND is used to calculate the distance required to escape out of a region, provided the position coordinates (x, y, z), direction cosine coordinates (α, β, γ), and region are known.

3. RFIND--Subroutine of Chain Two

Given the position coordinates (x, y, z), RFIND locates the region index (the region number used to identify the particular region).

4. RNEXP--Subroutine of Chain Two

RNEXP selects the number of mean free paths to be traveled by a particle from an exponential distribution.

5. ANAEST--Subroutine of Chain Two

ANAEST is used in performing the analytic estimation calculation (Appendix G). The answers resulting from analytic estimation tallies are made in ANAEST.

6. SPLT--Subroutine of Chain Two

SPLT keeps track of the number of particles to be followed resulting from a collision in a region where splitting (Chapter II) will occur.

7. COLISN--Subroutine of Chain Two

COLISN determines the type of interaction a particle will experience, and makes provision to either follow the particle if the event is a scattering or fission event or to select a new particle to follow if the event is an absorption.

8. COORDA--Subroutine of Chain Two

COORDA picks the direction cosines of the particles that are starting their life histories, that have suffered an elastic collision, or that have resulted from fission. The direction the particle takes is taken from an isotropic distribution.

9. RANNO--Subroutine of Chain Two

RANNO generates random numbers.

C. CHAIN 3

1. ANSWER--Main Program of Chain Three

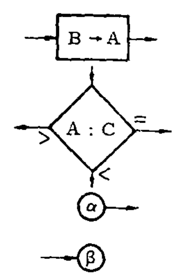
ANSWER converts some of the results to a more meaningful form, and writes the results on an output tape.

APPENDICES

APPENDIX A

FLOW DIAGRAMS

1. Flow Diagram Notation



Normal box--no decision is made.
Example: The quantity B is calculated or obtained in any other manner; then A is set equal to B.

Decision box
Example: If A < C, an exit occurs downward; if A = C, an exit is made to the right; and if A > C, an exit is made to the left.

Entry box
(Enter from an α exit box.)

Exit box
(Exit to β entry box.)

2. Flow Diagrams

The flow diagrams are as follows:

(1) PPREP (Fig. A-1)

(2) Subroutine TAPID (Fig. A-2)

(3) MAIN (Fig. A-3)

(4) Subroutine SFIND (Fig. A-3)

(5) Subroutine RFIND (Fig. A-5)

(6) Subroutine RNEXP (Fig. A-6)

(7) Subroutine ANAEST (Fig. A-7)

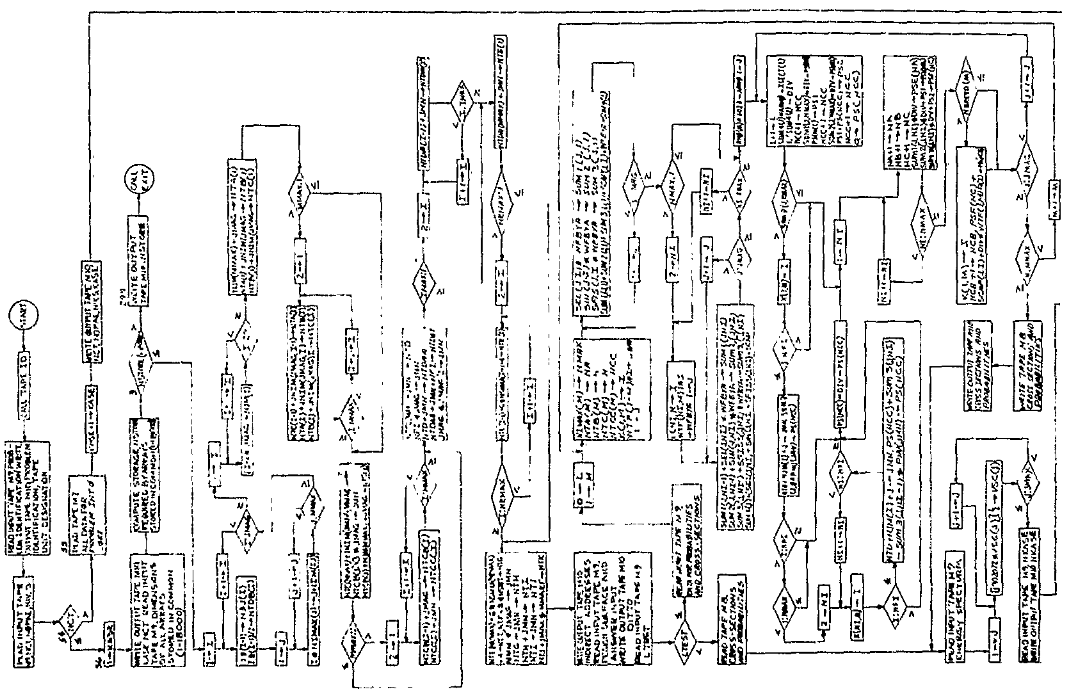
(8) Subroutine SPLT (Fig. A-8)

(9) Subroutine COLISN (Fig. A-9)

(10) Subroutine COORDA (Fig. A-10)

(11) Subroutine RANNO (Fig. A-11)

(12) ANSWER (Fig. A-12)



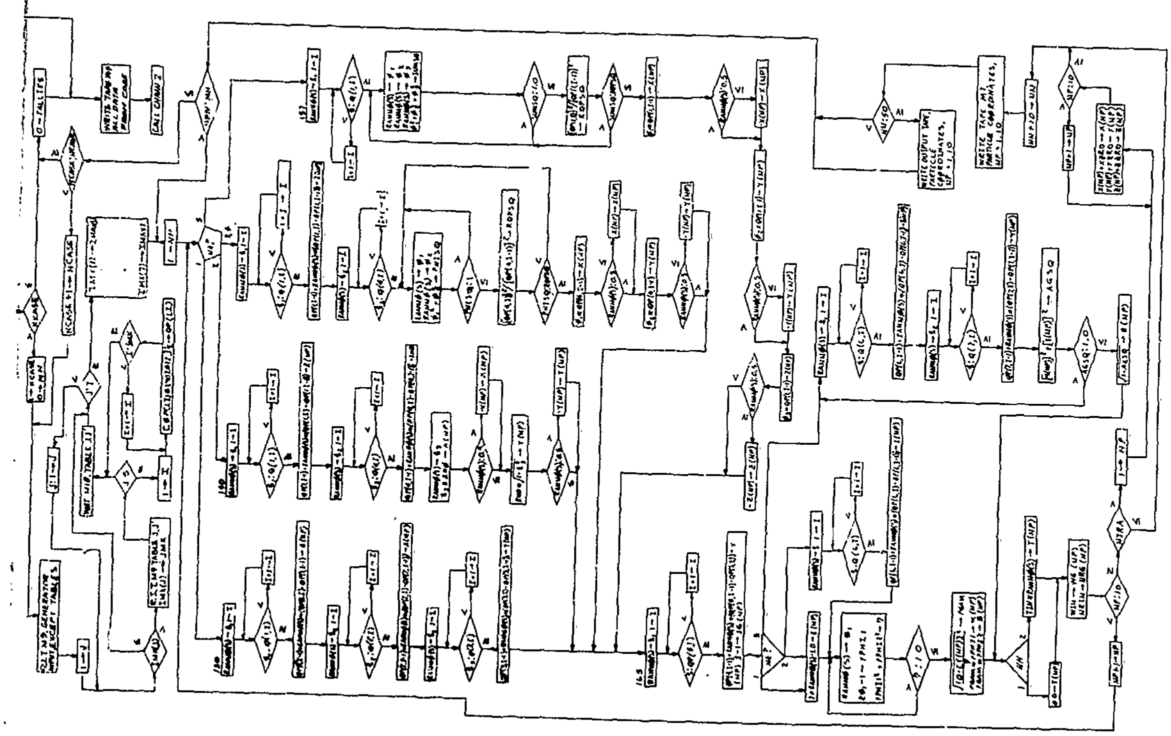


Fig. A-1. PPREP

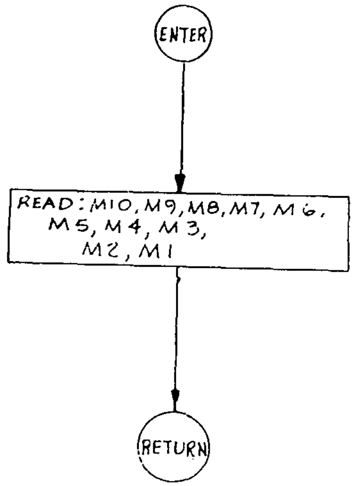
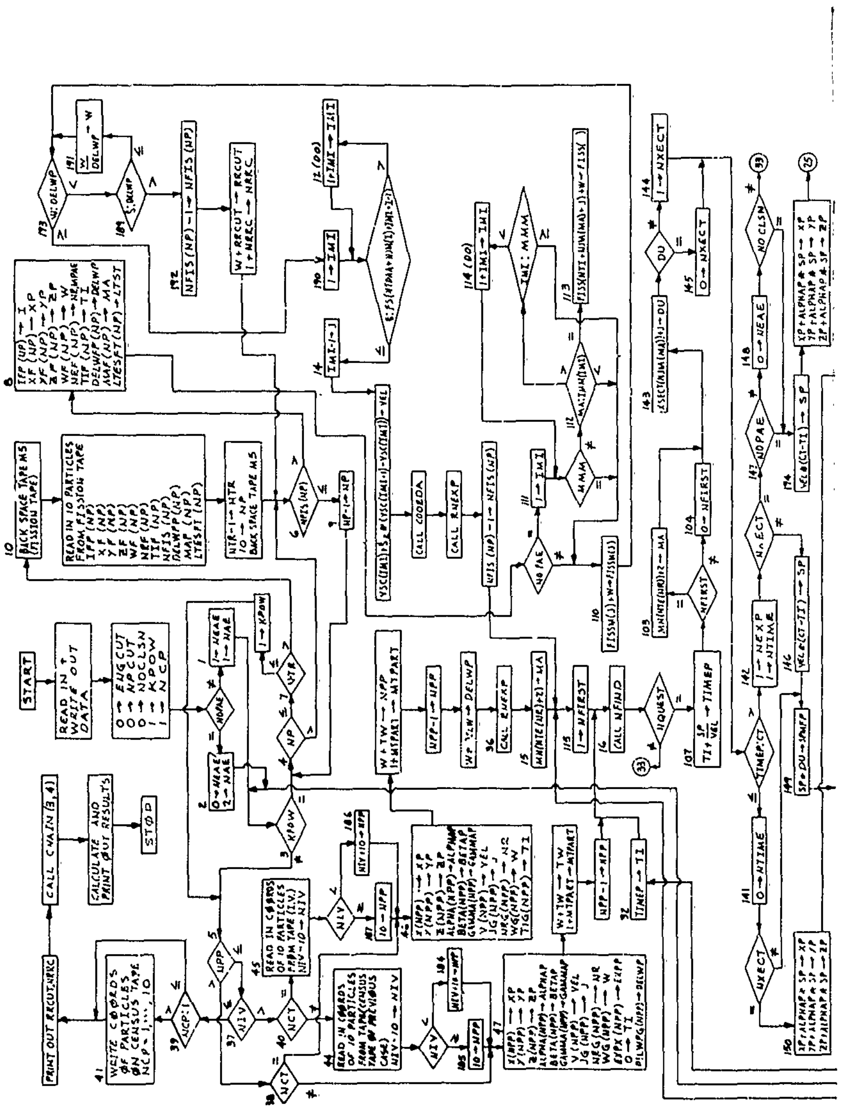


Fig. A-2. Subroutine TAPID


START
READ IN + WRITE OUT DATA
CALL CHAIN (3,4)
CALCULATE AND PRINT OUT RESULTS
STOP
CALL COORDA
CALL RNEXP
CALL NFIND

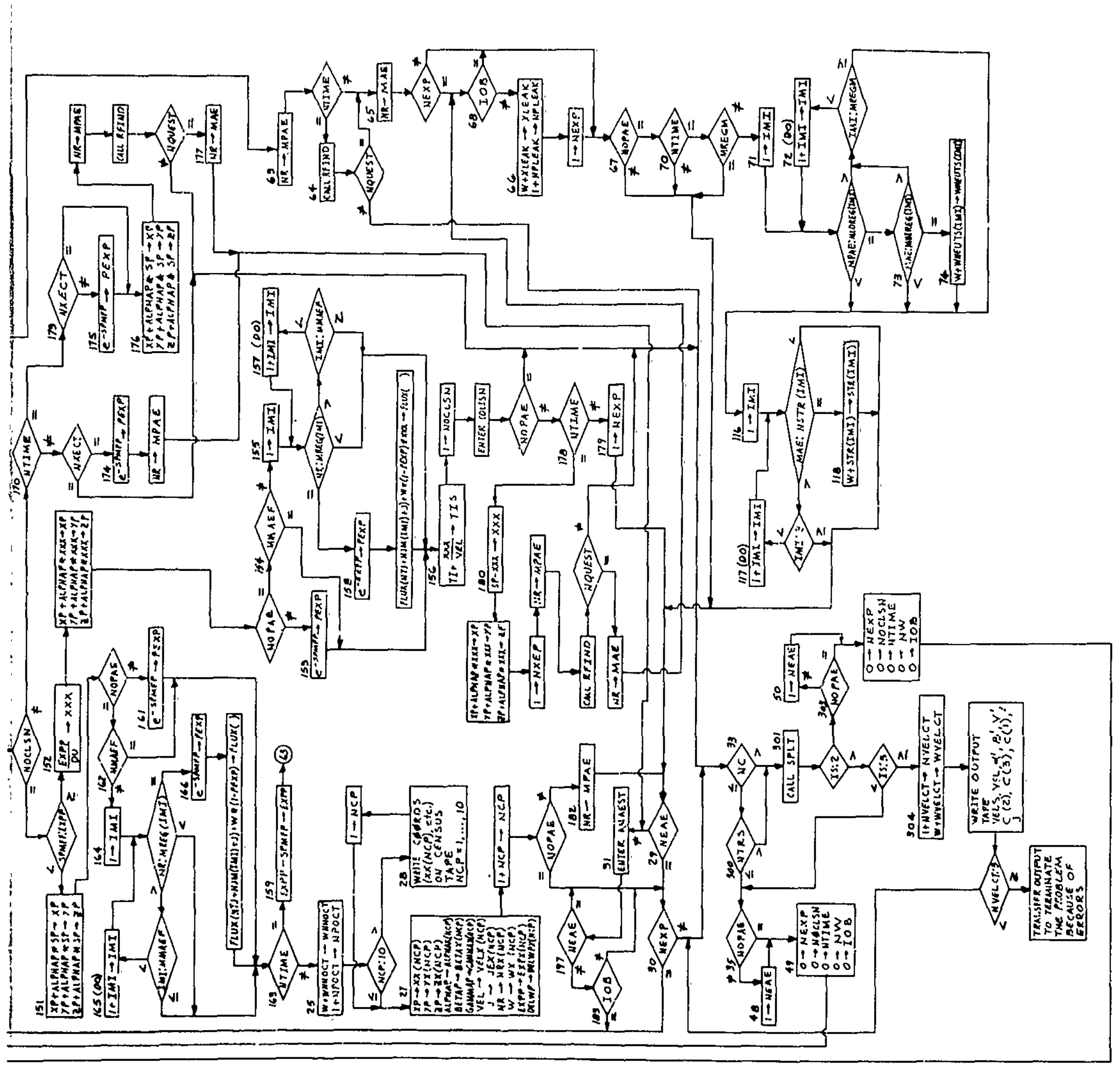


Fig. A-3.

MND-MC-2856

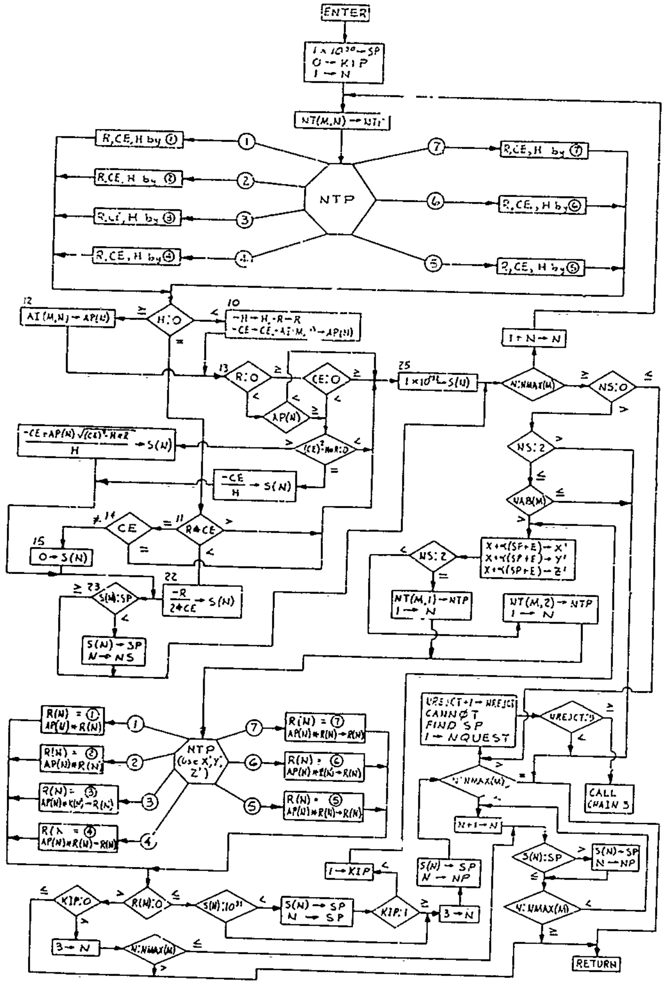


Fig. A-4. Subroutine SFIND

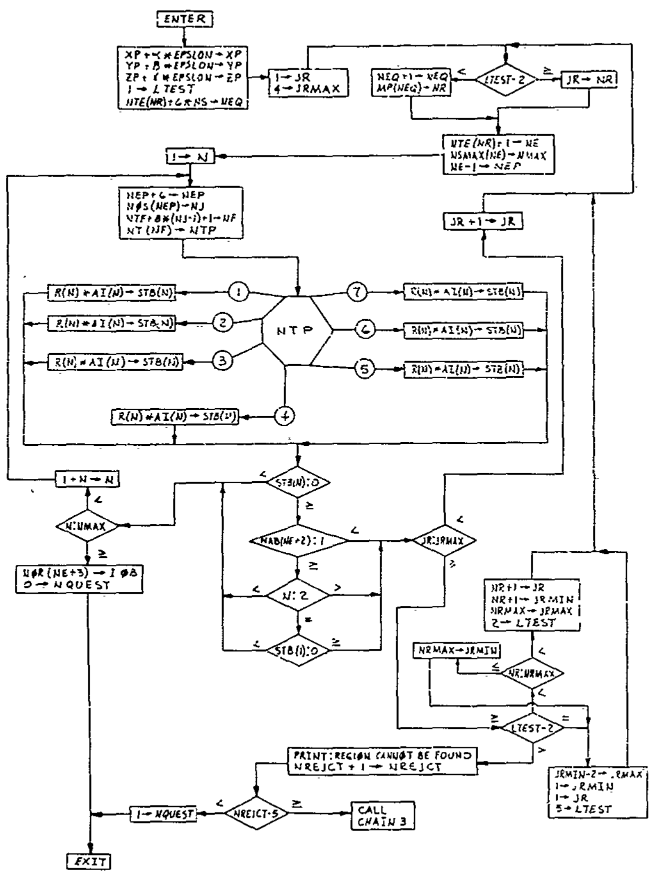


Fig. A-5. Subroutine RFIND

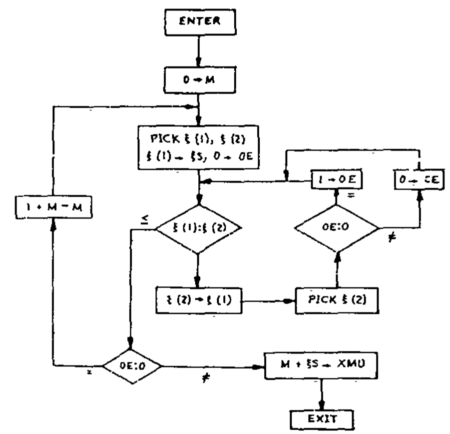


Fig. A-6. Subroutine RJEXP

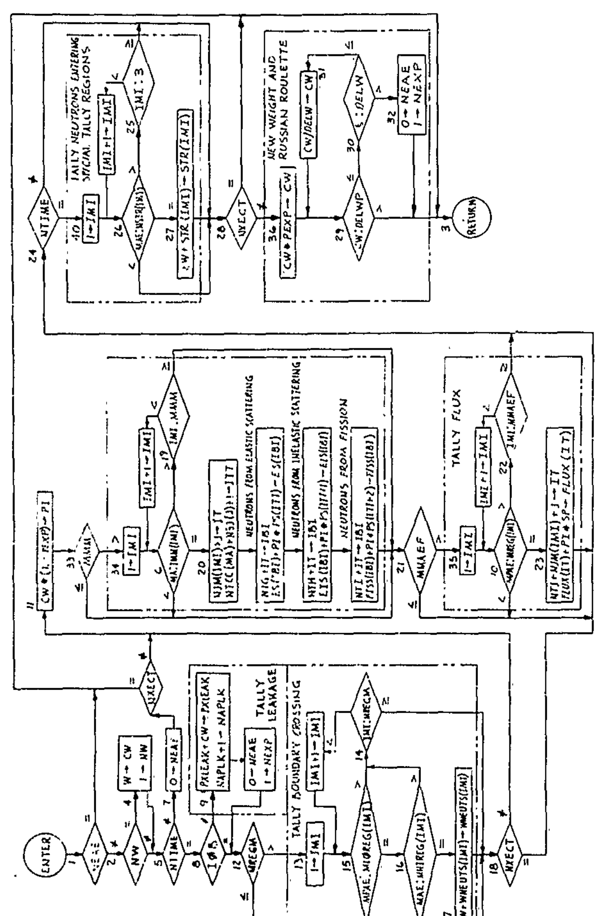


Fig. A-7. Subroutine ANAEST

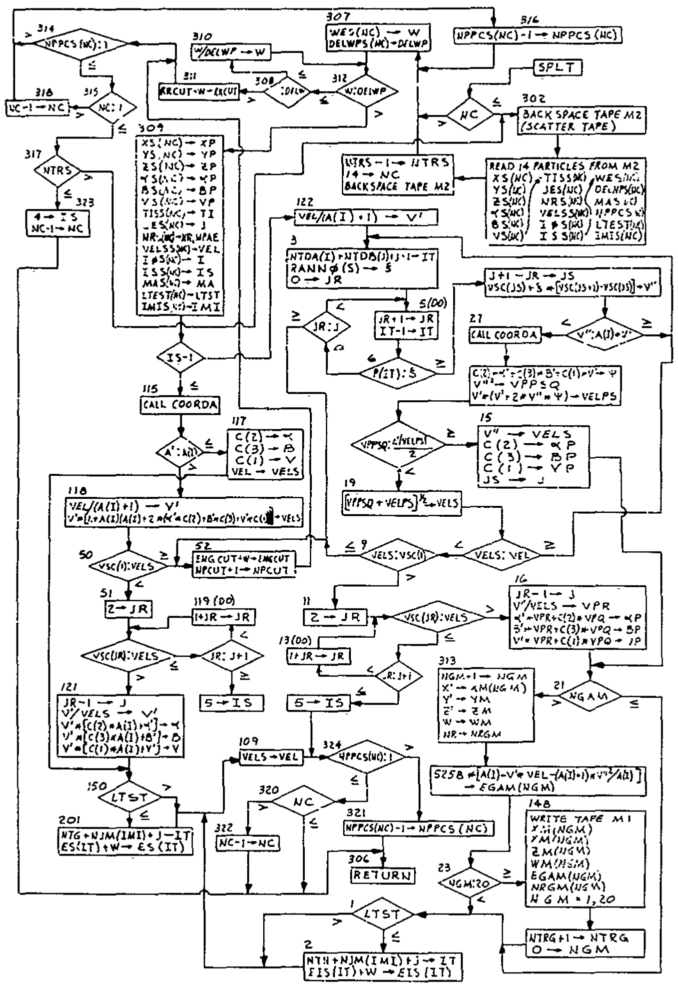


Fig. A-8. Subroutine SPLT

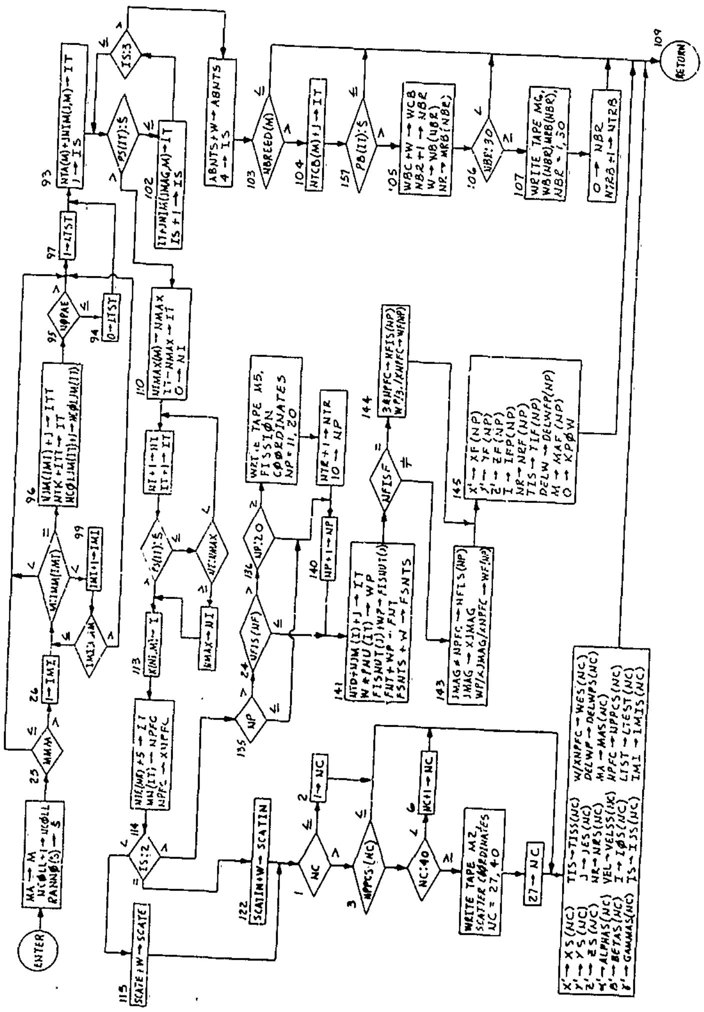


Fig. A-9. Subroutine COLISN

A-3.

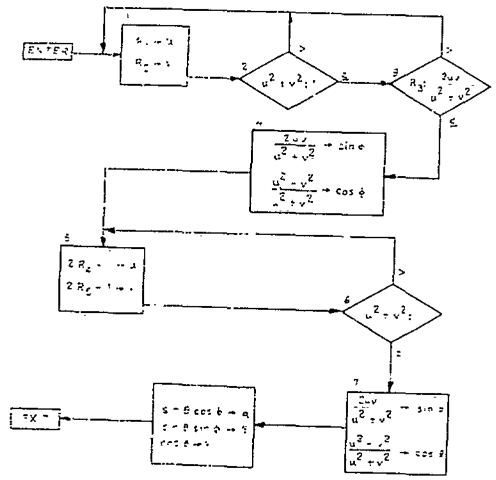


Fig. A-10. Subroutine COORDA

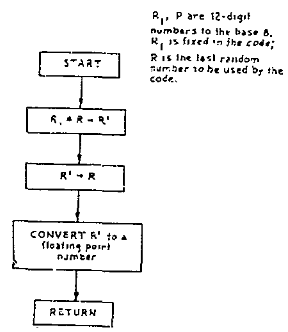


Fig. A-11. *Subroutine RANNO*

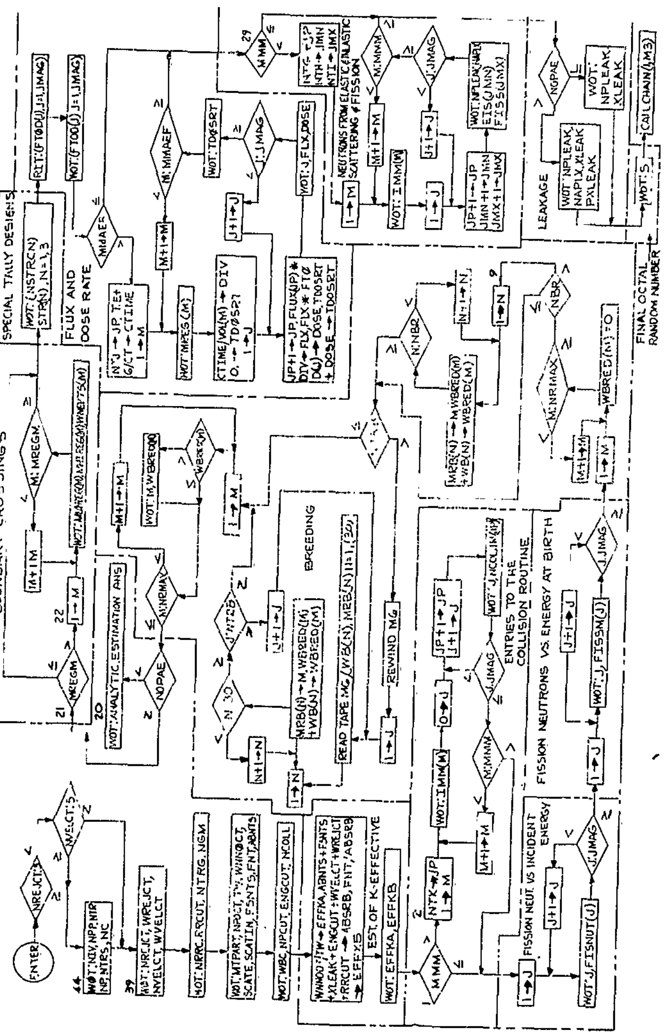


Fig. A-12. ANSWER

APPENDIX B

DEFINITION OF TERMS

A(I)	Atomic weight of isotope I
ABNTS	Number of neutrons absorbed
AC(NS)	A--of equations of surface (see geometry)
AI(NR, N)	Ambiguity index of surface N = 1.0 if N is outside surface = -1.0 if N is inside surface
AIP	= AI(NR, N), intermediate storage for ambiguity index
ALPHAP, BETAP, GAMMAP	Direction cosines of particle
ALPHAS, BETAS, GAMMAS	Direction cosines of scattered particle
APRIME	Light-heavy scattering cutoff
ARHO	= $.6023 \times 10^{24} \times 10^{-24}$
BC(NS)	B--of equations of surface (see geometry)
C(i) I = 1, 2, 3	Direction cosines from COORDA
CC(NS)	C--of equations of surface (see geometry)
CT	Census time
CW	Weight of particle in ANAEST
DELW	Minimum weight cutoff (input)
DIV	= 1/SUM 4(J) used in calculating PSE, PSI, PSF, XSECT
EGAM(NGM)	Energy of inelastic scattering gamma

ENGCUT	Number of neutrons below energy cutoff
FISNUT(J)	Number of neutrons born in fission process for each energy group J (straight Monte Carlo result)
FLUX(NR, J)	Average flux in a region (neutrons/cm^2-sec)
FS(J, I)	Fission spectrum (input)
I	Isotope number
IFP(NP)	Code No. of isotope that causes fission (used to store isotope code No. in fission part of COLISN)
IMAX	Maximum number of isotopes for all material $\leq$ 10
IMAX 1, IMAX 2, IMAX 7	Intermediate calculation--limits of tables used in generator
IMM(k)	Code No. of materials for which a tally is made of the neutrons arising from fission, elastic, and inelastic scattering
IMX(J)	Number of entries in Jth Q-QP table pairs
IOB	= 0; particle did not enter outside region = 1; particle did not enter outside region
IS	Interaction index 1--elastic 3--fission 2--inelastic 4--absorption
IT	Location in common area
J	Energy group index
JES	Energy group index of scattered particle
JG(k)	Energy group index as brought in from IV tape
JMAG	Maximum number of energy groups $\leq$ 32
JMAX	Number of energy levels = JMAG + 1

JNIM(J, M)	Used to interpolate in indirectly addressed arrays
JR JRMAX JRMIN	Used in DO LOOP in locating next region (RFIND)
K2, K2M	Limits used in writing PS
K(NI, M)	Identification of the isotope in material M
KPOW	= 0; take particle to be followed from fission neutrons (if any) = 1; take particle to be followed from I.V. or generator tape
L	Used in storing XSECT (J, M)
LTEST	Used in finding next region
M, MA	Material number
MAE, MPAE	Region indices used in ANAEST
MHIREG(k) MLOREG(k)	Used to tally the number of neutrons crossing boundaries
MMAEF	Maximum number of regions in which flux is tallied (input). MMAEF $\leq$ 20
MMAX	Maximum number of materials ($\leq$10)
MMM	Maximum number of materials in which the number of particles due to elastic and inelastic collisions are tallied. MMM $\leq$ 10
MN(NR)	Material No. for region NR.
MP(NR, N, K)	Kth most probable next region for particle through surface N of region NR (K = 1, 2, 3, and 4)
MREG(k)	Region code Nos. in which the flux is to be tallied. (input)

MRB	Tags the region as one which is used for breeding
MREGM	The number of pairs of MLOREG, MHIREG (input). MREGM $\leq$ 10
NA	= NTA(M) used to store PSE
NA, NE, NH	Determine tables used in the particle generator
NAB(NR)	= 0; no ambiguous boundaries = 1; yes, ambiguous boundaries
NAE	Used in assigned GO TO, set in MAIN 1--go to ANAEST 2--do not go to ANAEST
NAPLK	Tally of number of neutrons escaping system by *going out of outer boundaries* by analytical estimations
NB	= NTB(M) used to store PSI
NBR	Number of breeding events in core storage
NBREED(M)	= 1; if NBREED is one, the number of particles W, the time TI and region number NR are stored so that the code can later adjust the number of fissionable materials. = 0; if NBREED is zero, this part of *the calculation is bypassed* (absorption).
NC	= NTC(M) used to store PSF
NCT	= 0; particles to be followed are obtained from the I. V. tape; i. e., the coordinates *were* generated in the *in the generator* = 1; *particles to be followed are obtained from the census tape* (CT); i. e., *the coordinates are those of* the particle that *have* exceeded the *census time* (input)

NCP	Counter (number of particles to be written on census tape)
ND	= NDT(M) used to store PS (intermediate storage)
NE	= NTE(NR) + 1 (used to locate arrays in common)
NEAE	Set internally by the code. If NEAE is 1, the ANAEST routine is entered; if NEAE is 0, the ANAEST routine is not entered. This ensures that the particle is not followed beyond census time. If CW $\leq$ DELW, NEAE = 0
NEUTS(k)	Tally of number of neutrons crossing specified boundaries in traveling from one region to another.
NEXP	= 0; census time has not been reached, or no collision has occurred, or particle has not escaped in SMC = 1; census time has been reached, or a collision has occurred, or the particle has escaped from the system in straight *Monte Carlo calculation.*
NFI	Number of isotopes that are fissionable (input). NFI $\leq$ 10
NFIS(NP)	Counter No. of particle to be followed whose origin is due to fission. Set internally in FISSION
NFISF	Index which indicates the scheme to be used in calculating the number of particles to be followed after fission occurs. 0 indicates that the code will follow 3 particles. 1 indicates that the code *will follow JMAG* particles. If 3 particles are followed, the weight will be $\frac{\nu}{3}$ * (the weight of particle which fissioned). If JMAG particles are followed the weight of each particle will be $\frac{\nu}{JMAG}$ *

	(weight of particle which fissioned), W is the number of neutrons arising from fission (input)
NGAM	Region for inelastic scattering gamma
NGM	Number of inelastic scattering gammas in core
NI	Isotope No. in material
NIMAX(M)	Total number of isotopes in material $M \leq 10$
NIV	Number of particles to be followed (on I. V. or census tape)
NJM(N)	NJM(N) = (N-1)* JMAG, N = 1, 2, . . . , 20 (table, calculated internally)
NKASE	Number of sets of generator input
NMAX	= NIMAX(M) (used for DO LOOP LIMIT) = NSMAX(NR) (used for DO LOOP LIMIT)
NOCLSN	= 0; enter COLISN routine = 1; do not enter COLISN routine (set internally)
NOR(NR)	= 0; NR is inside region = 1; NR is outside region
NOS(N, NR)	Surface number of the Nth surface of region NR
NP	Index for NFIS(NP), NP = 1, . . . , 10. When NP > 10 the coordinates of particles are written on a tape.
NPCUT	Tally of number of particles below energy cutoff.
NPIV	Total particles generated at the end of a given generator case
NPLEAK	Number of particles leaking from system (tallied in SMC)

NPOCT	Number of particles on census tape after census period (output)
NPP	Number of particles from I. V. tape that are in core and remain to be followed
NQP, NQ	Used in calculating indirect addresses
NR	Region No.
NRIN	Input region for the generator
NRG(k)	Region index as brought in from I.V. or generator tape (MAIN)
NRMAX	Number of regions
NRS	Region in which particle scattered
NS	Surface No.
NSMAX(NR)	Number of surfaces in region NR (≤ 6)
NSTOT	Number of unique surfaces
NSTR(k)	Region index of special tally regions (input), 3 special tally regions
NT(NS)	Surface type for surface NS. (NT = 1, 2, . . . , 7)
NTA(M)	Indirect address for PSE
NTB(M)	Indirect address for PSI
NTC(M)	Indirect address for PSF
NTCB(M)	Indirect address for PB
NTD(M)	Indirect address for PS
NTE(NR)	Indirect address for arrays indexed on NR
NTIME	= 0; CT not exceeded = 1; CT exceeded

NTM, NT	Used in writing items stored in common
NTPART	Total number of particles on I. V. tape before census period
NTR	Counter on number of records of particles born in fission that are on tape
NTRA	Generator translation option
NTRB	Records of 30 inelastic scattering gammas each on tape
NW	= 0; first time in ANAEST for particle = 1; --Nth time in ANAEST for particle, N > 1
$P(J^1, J, I)$	Inelastic scattering matrix
PB(J, M)	Probability of breeding--material M, energy group J (defined for first isotope only)
PEXP	$= e^{-\mu x}$
PI	$= CW(1-e^{-\mu x})$
PNU	The number of neutrons arising from fission (input)
PS(K, J, M)	Neutrons/interaction for type of interaction K = 1; elastic 2; inelastic 3; fission
PS1	Used in calculating PSI
PS2	Used in calculating PSF
PSE(NI, J, M)	Elastic scattering probability
PSF(NI, J, M)	Fission probability
PSI(NI, J, M)	Inelastic scattering probability
PSIB	Sine of polar angle between original and scattered particle directions
PSIE	Cosine of polar angle between original and scattered particle directions

PXLEAK	Tally number of particles escaping system (going out of outer boundaries) by analytical estimation
Q(J, I)	Cumulative probability tables--generator
QP(J, I)	Coordinate tables--generator
R(N)	Distance to surface N
RHO(M)	Density of material M (g/cm^3)
S	Octal random number
SCAP(K, I)	Capture cross section, energy group J, isotope I
SCATE	Number of neutrons scattered elastically
SCATIN	Number of neutrons scattered inelastically
SEL(J, I)	Elastic scattering cross section; energy group J, isotope I
SFIS(J, I)	Fission cross section: energy group J, isotope I
SIN(J, I)	Inelastic scattering cross section; energy group J, isotope I
S(N)	Distance to surface N
STR(k)	Tally of number of neutrons entering special tally regions
SUM 1(NI, J)	Intermediate storage used in calculating PSE
SUM 2(NI, J)	Intermediate storage used in calculating PSI
SUM 3(NI, J)	Intermediate storage used in calculating PSF
SUM 4(J)	Intermediate storage used in calculating XSECT

TI	Time particle stays in system (MAIN)
TIF(NP)	Time at which fission occurred
TIME	Time particle stays in system (MAIN)
TIMEP	Time particle stays in system (ANAEST)
TIN	Generator--input time
TIS	Time for scattered particle
TW	Total number of neutrons of I. V. tape before census period
VEL	Velocity of particle (cm/μsec)
VELP VELS VPP, VPQ, VPR	Intermediate calculation of scattered velocity
VSC(J)	End points of energy interval, J = 1, 2, ..., JMAG + 1; VSC(J) > VSC(J - 1) (input as energies in ev, and converted to velocities in cm/μsec)
W	Weight of particle
WB(k)	Weight, used in breeding portion of collision routine
WBC	Number of neutrons that form potentially fissionable material (absorption)
WF(NP)	Weight of fission particles
WFBYA	= WTF(NI, M)/A(I)
WG(k)	Weight of particle as brought in from I. V. or generator tape (MAIN)
WNNOCT	Number of neutrons on census tape after census period (output)
WP	Weight of particle from I. V. tape
WS	Weight of scattered particle

WTF(NI, M)	Weight fraction of the isotope
XK(NS)	K of equations of surface
XSECT(J, M)	Total macroscopic cross section (cm^{-1})
XF, YF, ZF	Coordinate of fission particles
XP, YP, ZP	Coordinate of I. V. particles
XS, YS, ZS	Coordinate of scattered particles
XX, YX, ZX ALPHAX, BETAX, GAMMAX, VELS, JEX, NRX, WS	Coordinates to be written on census tape in blocks of 10
XZ(NS) YZ(NS) ZZ(NS)	$\left.\begin{matrix} X_o \\ Y_o \\ Z_o \end{matrix}\right\}$ *of equation of surface*
XZRO YZRO ZZRO	*Translation coordinates in the generator*
ZETA	*Floating random number*

APPENDIX C

THE EXPONENTIAL DISTRIBUTION

The flow diagram in Appendix A titled RNEXP is used for obtaining numbers which have the following distribution:

$$f(d) = e^{-d} \quad \text{for} \quad 0 < d < \infty$$

These numbers are used by the program as the distance (in mean free paths) to collision. The numbers, ξ, are random numbers in the range (0, 1). This method is due to J. Von Neuman, and can be found in AECU 3259, "Applications of Monte Carlo," by Herman Kahn, The Rand Corporation, Santa Monica, California.

APPENDIX D

PROBABILITY DISTRIBUTION TABLES

Information, in tabular form, must be available on various distributions and must be available to the program during calculation and during operation of the generator. The calculation portion also requires information in this form.

The generator has available to it various probability distribution tables. These tables are used for determining the values of various coordinates of the particles. The generator options determine which of the tables will be used and how they will be used. The coordinates of a particle, which are fixed in the generator and which may depend on these tables, are the position, velocity, and directional cosines.

All the probability distribution tables are of the same form with the exception of the *inelastic scattering* distribution tables. Each table is made up of two separate parts. One part is a cumulative distribution function (cdf), H; the other part is the random variable, q. There are equal numbers of entries in each part of the table. If H(q) is the probability density function (pdf) normalized in the interval (q, q_n), then the following relation exists between a particular entry, H_i, and the corresponding q_i:

$$H_i = 1 - \int_{q_1}^{q_i} h(q)\, dq \qquad \text{(D-1)}$$

Therefore, $H_1 = 1.0$ and $H_n = 0.0$, where n is the number of entries in each half of the table.

In choosing a particular value of q from a table, two random numbers are used. Let ξ_1 and ξ_2 be the two numbers. Then, the value of i is found which

$$H_{i-1} < \xi < H_i$$

q is then accepted as the value of the random variable and is calculated according to the following equation:

$$q = q_{i-1} + \xi_2 (q_i - q_{i-1}) \qquad \text{(D-2)}$$

The effect of representing a pdf in this tabular form and of choosing q in the manner described above is to reduce it to a histogram having n-1 intervals. This is illustrated in Fig. D-1.

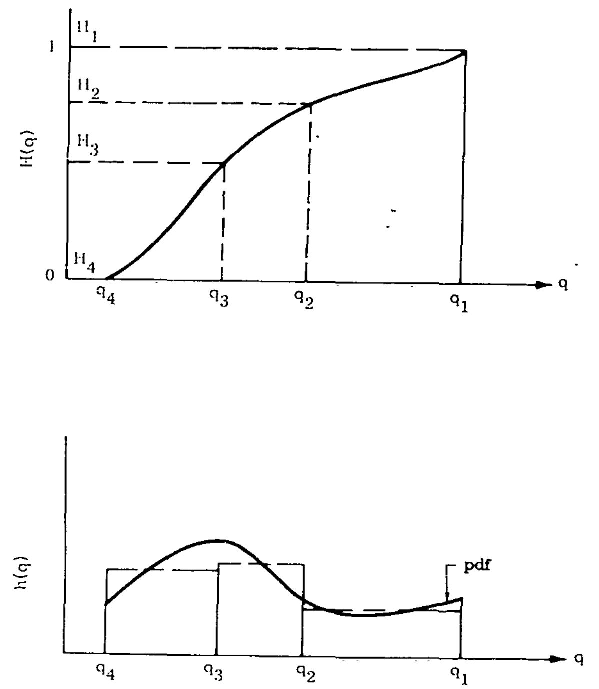


Fig. D-1. Histogram of Probability Distributions

APPENDIX E

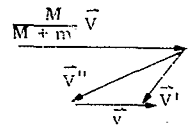
ISOTROPIC DISTRIBUTION IN SPACE

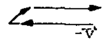
If α', β', and γ' are directional cosines, the direction they define will be isotropically distributed if the directional cosines are obtained in the manner described by the flow diagram labeled COORDA in Appendix A.

APPENDIX F

SCATTERING

All scattering is assumed to be isotropic in the center of mass (CM) system.





α, β, γ = directional cosines in the laboratory system (L)

$\alpha'', \beta'', \gamma''$ = directional cosines in the CM system after collision

α', β', γ' = directional cosines in the L system after collision.

where

α'', β'' and γ'' are chosen from an isotropic distribution (Appendix H)

m = projectile mass

M = target mass

V = speed of the projectile before collision in the L system

v = speed of the CM system with respect to L system

V''' = speed of the projectile before collision in CM system

V'' = speed of the projectile after collision in CM system

V' = speed of the projectile after collision in L system.

The speed, v, is taken as that of the target before collision in the CM system. The speed of the projectile in the CM system before collision (V''') can be found as a function of m, M, and v by using the fact that momentum is conserved in the CM system:

$$m V''' = M v$$

$$V''' = \frac{M}{m} v$$

and that momentum is conserved before collision between the CM and L systems:

$$m V = (m + M) v$$

$$v = \frac{m}{M + m} V.$$

Then

$$V''' = \frac{M}{m} v = \frac{M}{m} \left(\frac{m}{M + m}\right) V$$

$$= \frac{M}{M + m} V.$$

The directional cosines and the speed in the L system after collision can be found as a function of (α'', β'', γ''), (α, β, γ), V'', v, m, and M by the following means:

$$\overline{V'} = \overline{V''} + \overline{v}.$$

Since $v = \frac{m}{m + M} V$, and unit vectors

$$\hat{v} = \hat{V}, \text{ then}$$

$$\overline{V'} = \overline{V''} + \frac{m}{M + m} \overline{V}$$

$= \alpha' V' \hat{i} + \beta' V' \hat{j} + \gamma' V' \hat{k}$; $\hat{i}$, $\hat{j}$, $\hat{k}$ are unit orthogonal vectors.

$$= (\alpha'' V'' + \alpha \frac{m}{m + M} V)\hat{i} + (\beta'' V'' + \beta \frac{m}{m + M} V)\hat{j}$$

$$+ (\gamma'' V'' + \gamma \frac{m}{m + M} V)\hat{k}.$$

Then $V'^2 = (V''^2 + \left(\frac{m}{M + m}\right)^2 V^2 + 2 \frac{m}{M + m} (\alpha''\alpha + \beta''\beta + \gamma''\gamma) V'' V$

and

$$V' = \left[V''^2 + \left(\frac{1}{A + 1}\right)^2 V^2 + 2 \frac{1}{A + 1} (\alpha''\alpha + \beta''\beta + \gamma''\gamma) V'' V\right]^{1/2} \tag{G-1}$$

Therefore,

$$\alpha' = \frac{\alpha'' V'' + \alpha \frac{1}{A + 1} V}{V} \tag{G-2}$$

$$\beta' = \frac{\beta'' V'' + \beta \frac{1}{A + 1} V}{V} \tag{G-3}$$

$$\gamma' = \frac{\gamma'' V'' + \gamma \frac{1}{A + 1} V}{V} \tag{G-4}$$

where

$$\frac{m}{M + m} = \frac{1}{A + 1}.$$

1. Case 1--Elastic Scattering

$$V'' = \frac{M}{M + m} V = \frac{A}{A + 1} V.$$

Then

$$V' = \frac{V}{A + 1} \left[A^2 + 1 + 2A (\alpha''\alpha + \beta''\beta + \gamma''\gamma)\right]^{1/2} \tag{G-5}$$

$$\alpha' = (\alpha'' A + \alpha) \frac{1}{A + 1} \frac{V}{V'} \tag{G-6}$$

$$\beta' = (\beta'' A + \beta) \frac{1}{A + 1} \frac{V}{V'} \tag{G-7}$$

$$\gamma' = (\gamma'' A + \gamma) \frac{1}{A + 1} \frac{V}{V'}. \tag{G-8}$$

2. Case 2--Heavy Elastic Scattering

An option is provided in the code through the input of the number A^1 such that for $A_i \geq A^1$, the nucleus is assumed to have infinite mass. The equations then reduce to:

$$V' = V$$

$$\alpha' = \alpha''$$

$$\beta' = \beta''$$

$$\gamma' = \gamma''$$

3. Case 3--Inelastic Scattering

The velocity, V'', is assigned a value determined from the inelastic scattering matrix. Equations (F-1), (F-2), (F-3), and (F-4) are then used to calculate the velocity and direction cosines of the inelastically scattered neutron.

The change in internal energy of the target nucleus for inelastic scattering is the energy attributed to the gamma rays due to inelastic scattering.

$$E = \frac{m}{2}\left[\left(\frac{A_i}{A_i + 1}\right)^2 V^2 - V''^2\right] \tag{J-1}$$

$$E\,(ev) = 0.5258\left[\left(\frac{A_i}{A_i + 1}\right)^2 V^2 - V''^2\right] \tag{J-2}$$

where the velocities are in cm/μsec.

The coordinates of the gamma ray [x, y, z, region index, energy (ev) and weight of the particle after scattering) are stored on a tape (not the output tape] and are available for later use.

The calculation and writing of the inelastic gamma sources on tape are controlled by option NGAM (Card Type 8).

4. Case 4--Heavy Inelastic Scattering

The equations for the velocity and directions cosines after inelastic scattering reduce to:

$$V' = V''$$

$$\alpha' = \alpha''$$

$$\beta' = \beta''$$

$$\gamma' = \gamma''$$

for heavy inelastic scattering. However, the approximation is not only a function of A_i; it also depends on V and V''. For elastic scattering they are functionally related, but this is not the case in inelastic scattering.

For an error equivalent to that introduced in elastic scattering by the approximation of a nucleus with infinite mass, the following relation must hold for inelastic scattering.

$$V''^2 \geq \frac{A' * \left|\frac{V}{A_i + 1} * \left(\frac{V}{A_i + 1} + 2 * V'' * (\alpha\alpha'' + \beta\beta'' + \gamma\gamma'')\right)\right|}{2}$$

APPENDIX G

ANALYTIC ESTIMATION

A particle scattered elastically or inelastically, born in fission or starting its life history from some Cartesian coordinate (x, y, z) with direction cosines (α, β, γ) and with weight W has a certain probability of continuing in a straight line path (not changing direction cosines), remaining in the same energy group and making contributions to various answers. The term analytic estimation used in this report is taken to mean the above described process. The contributions each particle makes to the respective answers in the analytic estimation routine is terminated only when the particle escapes from the system, exceeds census time, or falls below the minimum weight cutoff. The contributions made to the respective answers are in the form of tallies. The tallies for the following are described in some detail:

(1) Number of particles and neutrons leaking from the system.

(2) Number of neutrons entering the special tally regions.

(3) Neutron flux versus region and energy group.

(4) Number of neutrons scattered elastically and inelastically versus material and energy group.

(5) Number of neutrons born in fission versus material and energy group.

(6) Numbers of neutrons crossing from Region ℓ to Region ℓ'.

1. Number of Particles and Neutrons Leaking from the System

The following tallies are made when a particle escapes from the system.

(G. 1) Weight of the particle * probability that the particle will reach the outer bound of the system:

$$W * e^{\sum_{i=1}^{m} \mu_i x_i}.$$

(G.2) 1 * Probability that the particle will reach the outer bound of the system = $1 * e^{-\sum_{i=1}^{n} \mu_i x_i}$, where $X_1, X_2, \ldots, X_n$ are the straight line distances through the regions traversed by the particle and $\mu_1, \mu_2, \ldots \mu_n$ are the total macroscopic cross sections of these regions. G.1 represents the contribution made to the number of neutrons leaking from the system, and G.2 represents the contributions to the numbers of particles leaking from the system.

2. Number of Neutrons Entering the Special Tally Regions

The following tally is made when the particle enters any one of the three special tally regions.

(G.3) Weight of the particle * Probability that the particle will reach the special tally region when the contribution is made = $W * e^{-\sum_{i=1}^{n} \mu_i x_i}$, where $X_1, X_2, \ldots, X_n$ are the distances traversed by the particle until it reaches the special tally region and $\mu_1, \mu_2, \ldots, \mu_n$ are the macroscopic cross sections associated with these regions.

3. Neutron Flux Versus Region and Energy Group

The following tally is made for the energy group occupied by the particle and if the region occupied by the particle is one for which the flux is to be tallied.

(G.4) $\dfrac{\text{Weight of particle x probability the particle will reach Region n * average path length through Region n}}{\text{Volume of Region n * census time}} =$

$$= \frac{W * e^{-\sum_{i=1}^{n-1} \mu_i x_i} * \frac{1}{\mu_n} (1 - e^{-\mu_n X_n})}{V_n * T},$$

5. Number of Neutrons Born in Fission Versus Material and Energy Group

The following tally is made for each energy group and material for which it is requested.

(G.7) Weight of particle * Probability the particle will reach Region n containing material m * Probability the event * Number of neutrons per fission =

$$W * e^{-\sum_{i=1}^{m-1} \mu_i x_i} * (1 - e^{-\mu_n X_n}) * PF_m * \nu$$

where μ_i, x_i are defined as above, and

PF_m = Probability that the event will be a fission event

ν = Number of neutrons released in fission.

6. Number of Neutrons Crossing from Region ℓ to Region ℓ'

The following tally is made for a particle crossing from Region to Region ℓ'.

(G.8) Weight of particle * Probability the particle will reach Region ℓ' =

$$W * (1 - e^{-\sum_{i=1}^{m} \mu_i x_i})$$

where μ_i, x_i are defined as above and X_n is the distance traveled through Region ℓ.

where

$X_1, X_2, \ldots, X_{n-1}$ = distances traveled by the particle to reach Region n

X_n = distance traveled by particle through Region n

$\mu_1, \mu_2, \ldots, \mu_n$ = macroscopic cross sections of the respective regions

V_n = volume of Region n

T = census time

The average path length through Region n, $(\overline{X})$ is obtained as follows:

$$\overline{X} = \int_0^{\overline{X}} e^{-\mu x}\, dx = (1 - e^{-\mu \overline{X}}), \quad \text{(G.5)}$$

where $\underline{X}$ is the actual distance traveled by the particle through Region n.

4. Number of Neutrons Scattered Elastically and Inelastically Versus Material and Energy Group

The following tally is made for each energy group and material for which it is requested.

(G.6) Weight of particle * Probability that the particle will reach the region containing the material* Probability that the particle will be stopped in the region * Probability that the event will be an $\begin{pmatrix}\text{elastic} \\ \text{inelastic}\end{pmatrix}$ event =

$$W * e^{-\sum_{i=1}^{m-1} \mu_i x_i} * (1 - e^{-\mu_n X_n}) * \begin{pmatrix} PE_m \\ PI_m \end{pmatrix},$$

where the μ_i and x_i are defined as above, and

PE_m = Probability that the event will be an elastic scattering with material m

PI_m = Probability that the event will be an elastic scattering with material m.

APPENDIX H

MAP OF COMMON 1 TO 18,000 INDIRECT ADDRESSES

Quantity	Location in Common
XSECT(1,1)	XSECT(NJM(1)+1)
⋮	
XSECT(J,1)	XSECT(NJM(1)+J)
⋮	
XSECT(JMAG,1)	XSECT(NJM(1)+JMAG)
⋮	
XSECT(J,M)	XSECT(NJM(M)+J)
⋮	
XSECT(JMAG,MMAX)	XSECT(NJM(MMAX)+JMAG)
PSE(1,1,1)	PSE(NTA(1)+JNIM(1,1)+1)
⋮	
PSE(NI,1,1)	PSE(NTA(1)+JNIM(1,1)+NI)
⋮	
PSE(NIMAX(1),1,1)	PSE(NTA(1)+JNIM(1,1)+NIMAX(1))
⋮	
PSE(NI,J,1)	PSE(NTA(1)+JNIM(J,1)+NI)
⋮	
PSE(NIMAX(1),JMAG,1)	PSE(NTA(1)+JNIM(JMAG,1)+NIMAX(1))
PSI(1,1,1)	PSI(NTB(1)+JNIM(1,1)+1)
⋮	
PSI(NI,J,1)	PSI(NTB(1)+JNIM(J,1)+NI)
⋮	
PSI(NIMAX(1),JMAG,1)	PSI(NTB(1)+JNIM(JMAG,1)+NIMAX(1))
PSF(1,1,1)	PSF(NTC(1)+JNIM(1,1)+1)
⋮	
PSF(NI,J,1)	PSF(NTC(1)+JNIM(J,1)+NI)
⋮	
PSF(NIMAX(1),JMAG,1)	PSF(NTC(1)+JNIM(JMAG,1)+NIMAX(1))
⋮	
PSE(NI,J,M)	PSE(NTA(M)+JNIM(J,M)+NI)
⋮	

Quantity	Location in Common
PNU(J, 1)	PNU(NTD+NJM(1)+J)
⋮	
PNU(JMAG, 1)	PNU(NTD+NJM(1)+JMAG)
⋮	
PNU(J, I)	PNU(NTD+NJM(I)+J)
⋮	
PNU(JMAG, NFI)	PNU(NTD+NJM(NFI)+JMAG)
FS(1, 1)	FS(NTDAA+NJM(1)+1)
⋮	
FS(J, 1)	FS(NTDAA+NJM(1)+J)
⋮	
FS(JMAX, 1)	FS(NTDAA+NJM(1)+JMAX)
⋮	
FS(J, I)	FS(NTDAA+NJM(I)+I+J-1)
⋮	
FS(JMAX, NFI)	FS(NTDAA+NJM(NFI)+NFI+JMAX-1)
P(1, 1, 1)	P(NTDA(1)+NTDB(1)+1)
P(1, 2, 1)	P(NTDA(1)+NTDB(2)+1)
P(2, 2, 1)	P(NTDA(1)+NTDB(2)+2)
⋮	
P(1, J, 1)	P(NTDA(1)+NTDB(J)+1)
⋮	
P(J', J, 1)	P(NTDA(1)+NTDB(J)+J')
⋮	
P(J, J, 1)	P(NTDA(1)+NTDB(J)+J)
⋮	
P(J; JMAG, 1)	P(NTDA(1)+NTDB(JMAG+J')
⋮	
P(JMAG, JMAG, 1)	P(NTDA(1)+NTDB(JMAG)+JMAG)
⋮	
P(J', J, I)	P(NTDA(I)+NTDB(J)+J')
⋮	
P(JMAG, JMAG, IMAX)	P(NTDA(IMAX)+NTDB(JMAG)+JMAG)
NSMAX(1)	NSMAX(NTE(1)+1)
MN(1)	MN(NTE(1)+2)
NAB(1)	NAB(NTE(1)+3)
NOR(1)	NOR(NTE(1)+4)
NPFC(1)	NPFC(NTE(1)+5)

Quantity	Location in Common
PSI(NI, J, M)	PSI(NTB(M)+JNIM(J, M)+NI)
⋮	
PSF(NI, J, M)	PSF(NTC(M)+JNIM(J, M)+NI)
⋮	
PSE(NIMAX(MMAX), JMAG, MMAX)	PSE(NTC(MMAX)+JNIM(JMAG, MMAX) +NIMAX(MMAX))
⋮	
PSI(NIMAX(MMAX), JMAG, MMAX)	PSI(NTB(MMAX)+JNIM(JMAG, MMAX) +NIMAX(MMAX))
⋮	
PSF(NIMAX(MMAX), JMAG, MMAX)	PSF(NTC(MMAX)+JNIM(JMAG, MMAX) +NIMAX(MMAX))
PB(1, 1)	PB(NTCB(1)+1)
⋮	
PB(J, 1)	PB(NTCB(1)+J)
⋮	
PB(JMAG, 1)	PB(NTCB(1)+JMAG)
⋮	
PB(J, M)	PB(NTCB(M)+J)
⋮	
PB(JMAG, MMAX)	PB(NTCB(MMAX)+JMAG)
PS(1, 1, 1)	PS(NTCC(1)+N3J(1)+1)
PS(2, 1, 1)	PS(NTCC(1)+N3J(1)+2)
PS(3, 1, 1)	PS(NTCC(1)+N3J(1)+3)
⋮	
PS(1, J, 1)	PS(NTCC(1)+N3J(J)+1)
PS(2, J, 1)	PS(NTCC(1)+N3J(J)+2)
PS(3, J, 1)	PS(NTCC(1)+N3J(J)+3)
⋮	
PS(1, JMAG, 1)	PS(NTCC(1)+N3J(JMAG)+1)
PS(2, JMAG, 1)	PS(NTCC(1)+N3J(JMAG)+2)
PS(3, JMAG, 1)	PS(NTCC(1)+N3J(JMAG)+3)
⋮	
PS(1, J, M)	PS(NTCC(M)+N3J(J)+1)
PS(2, J, M)	PS(NTCC(M)+N3J(J)+2)
PS(3, J, M)	PS(NTCC(M)+N3J(J)+3)
⋮	
PS(1, JMAG, MMAX)	PS(NTCC(MMAX)+N3J(JMAG)+1)
PS(2, JMAG, MMAX)	PS(NTCC(MMAX)+N3J(JMAG)+2)
PS(3, JMAG, MMAX)	PS(NTCC(MMAX)+N3J(JMAG)+3)
PNU(1, 1)	PNU(NTD+N)JM(1)+1)
⋮	

Quantity	Location in Common
AI(1, 1)	AI(NTE(1)+6)
NOS(1, 1)	NOS(NTE(1)+7)
MP(1, 1, 1)	MP(NTE(1)+8)
MP(Z, 1, 1)	MP(NTE(1)+9)
MP(3, 1, 1)	MP(NTE(1)+10)
MP(4, 1, 1)	MP(NTE(1)+11)
⋮	
AI(NJ, 1)	AI(NTE(1)+6xNJ)
⋮	
MP(4, NJ, 1)	MP(NTE(1)+6xNJ+5)
⋮	
AI(NSMAX(1), 1)	AI(NTE(1)+6xNSMAX(1))
⋮	
MP(4, NSMAX(1), 1)	MP(NTE(1)+6xNSMAX(1)+5)
⋮	
NSMAX(NR)	NSMAX(NTE(NR)+1)
⋮	
NPFC(NR)	NPFC(NTE(NR)+5)
AI(1, NR)	AI(NTE(NR)+6)
⋮	
MP(4, 1, NR)	MP(NTE(NR)+11)
⋮	
AI(NSMAX(NR), NR)	AI(NTE(NR)+6xNSMAX(NR))
⋮	
MP(4, NSMAX(NR), NR)	MP(NTE(NR)+6xNSMAX(NR)+5)
NSMAX(NRMAX)	NSMAX(NTE(NRMAX)+1
⋮	
MP(4, NSMAX(NRMAX), NRMAX)	MP(NTE(NRMAX)+6xNSMAX(NRMAX+5)
NT(1)	NT(NTF+1)
AC(1)	AC(NTF+2)
BC(1)	BC(NTF+3)
CC(1)	CC(NTF+4)
XK(1)	XK(NTF+5)
XZ(1)	XZ(NTF+6)
YZ(1)	YZ(NTF+7)
ZZ(1)	ZZ(NTF+8)
⋮	
NT(NS)	NT(NTF+8x(NS-1)+1)
⋮	

Quantity	Location in Common
ZZ(NS)	ZZ(NTF+8x(NS-1)+8)
⋮	
NT(NSTOT)	NT(NTF+8x(NSTOT-1)+1)
⋮	
ZZ(NSTOT)	ZZ(NTF+8x(NSTOT-1)+8)
ES(1, 1)	ES(NTF+NJM(1)+1)
⋮	
ES(J, 1)	ES(NTG+NJM(1)+J)
⋮	
ES(JMAG, 1)	ES(NTG+NJM(1)+JMAG)
⋮	
ES(J, M)	ES(NTG+NJM(M)+J)
⋮	
ES(JMAG, MMM)	ES(NTG+NJM(MMM)+JMAG)
EIS(1, 1)	EIS(NTH+NJM(1)+1)
⋮	
EIS(J, 1)	EIS(NTH+NJM(1)+J)
⋮	
EIS(JMAG, 1)	EIS(NTH+NJM(1)+JMAG)
⋮	
EIS(J, M)	EIS(NTH+NJM(M)+J)
⋮	
EIS(JMAG, MMM)	EIS(NTH+NJM(MMM)+JMAG)
FISS(1, 1)	FISS(NTI+NJM(1)+1)
⋮	
FISS(J, 1)	FISS(NTI+NJM(1)+J)
⋮	
FISS(JMAG, 1)	FISS(NTI+NJM(1)+JMAG)
⋮	
FISS(J, M)	FISS(NTI+NJM(M)+J)
⋮	
FISS(JMAG, MMM)	FISS(NTI+NJM(MMM)+JMAG)
FLUX(1, 1)	FLUX(NTJ+NJM(1)+1)
⋮	
FLUX(J, 1)	FLUX(NTJ+NJM(1)+J)
FLUX(JMAG, 1)	FLUX(NTJ+NJM(1)+JMAG)
⋮	

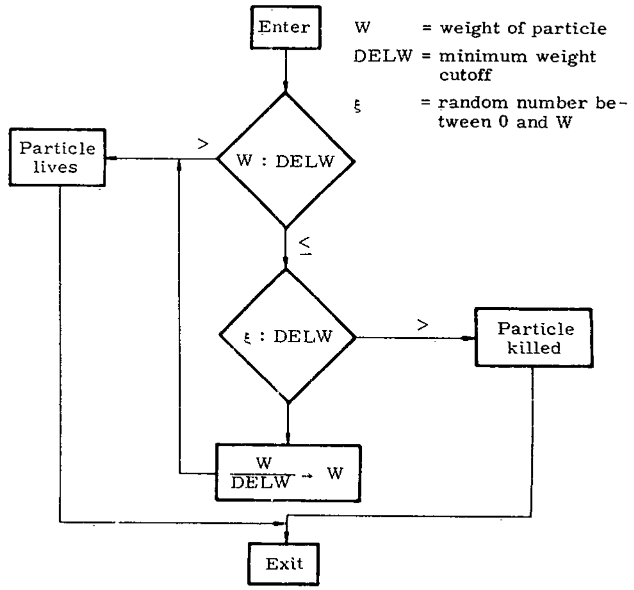
Quantity	Location in Common
FLUX(J,NR)	FLUX(NTJ+NJM(NR)+J)
⋮	
FLUX(JMAG,MMAEF)	FLUX(NTJ+NJM(MMAEF)+JMAG)
NCOLJM(1,1)	NCOLJM(NTI+NJM(1)+1)
⋮	
NCOLJM(J,1)	NCOLJM(NTI+NJM(1)+J)
⋮	
NCOLJM(JMAG,1)	NCOLJM(NTI+NJM(1)+JMAG)
⋮	
NCOLJM(J,M)	NCOLJM(NTI+NJM(N)+J)
⋮	
NCOLJM(JMAG,MMM)	NCOLJM(NTI+NJM(MMM)+JMAG)

APPENDIX I

RUSSIAN ROULETTE

Russian roulette is used in the code to ensure that the weight of the particles does not fall below a minimum weight, below which the particle contributions to the various tallies would not be significant and therefore not worth spending the calculation time to obtain the tallies.

If a particle's weight falls below a prescribed value, a game is played to determine if the particle should be "killed" and a new particle followed or if the particle should continue its "life." If the particle is allowed to "live," then it is given an extra weight to make up for the fact that some other particles may have been killed. The process is best described in a flow diagram.



125

APPENDIX J

STRAIGHT MONTE CARLO TALLIES

If the analytic estimation routine is not entered, the tallies described in Appendix H plus other additional tallies are made by means of straight Monte Carlo. The methods of obtaining these tallies are described below.

1. Number of Neutrons and Particles Leaking from the System

If a neutron particle escapes (leaks) from the system, 1 is added to the particle tally and W, the particle's weight, is added to the neutron tally.

2 Number of Neutrons Entering Special Tally Regions

If a particle enters a special tally region, W, the particle's weight, is added to the tally for that special tally region.

3. Estimation of Criticality

The criticality of the system for a particular time period is estimated by dividing the number of neutrons left at the end of the census period by the number for neutrons starting their life history for that census period.

4. Number of Neutrons Scattered, Elastically and Inelastically

If a particle scatters elastically or inelastically, W, the weight of the particle, is added to the respective tally.

5. Number of Neutrons Born Versus Energy

If a particle experiences a fission event, W * ν is tallied for the particular energy group the particle is in, where ν is the number of the particles emitted per fission for that particular energy group, W is the weight of the particle.

6. Number of Particles and Neutrons Starting Life Histories

One is added to the particle tally and W is added to the neutron tally of each particle starting their life history for the census period.

7. Number of Particles and Neutrons on Census Tape After Census Period

One is added to the particle tally and W is added to the neutron tally of the number of particles and neutrons on census tape immediately before the particle is written on the census tape.

8. Neutron Flux Versus Region and Energy Group

The following tally is made for the region and energy group occupied by the particle, if the region is one for which the flux is to be tallied.

$$\frac{\text{Weight of particle* average path length through the region}}{\text{Volume of the region*census time}} =$$

$$\frac{W*\frac{1}{\mu}(1 - e^{-\mu x})}{V*T}, \text{ where}$$

x = actual distance traveled in the region

μ = macroscopic cross section in the region.

9. Number of Neutrons Crossing from Region ℓ to Region ℓ'

If a particle travels from Region ℓ to Region ℓ' (two adjacent regions), W is added to the tally of neutrons crossing from Region ℓ to Region ℓ'.

10. Number of Neutrons Born in Fission or Scattered Elastically or Inelastically Versus Material and Energy Group

The tally for each of the three processes is made by adding W or W* to the correct tally as the particle experiences the event for the material and energy group in which the particle resides.

11. Number of Times the Collision Routine Was Entered Versus Material and Energy Group

One is added to the tally for the particular material and energy group in which the particle resides.

12. Number of Particles and Neutrons That Have Fallen Below the Energy Cutoff

One is added to the particle tally and W to the neutron tally when the energy of the particle falls below the energy cutoff.

13. Dose Rates Versus Region and Energy Group

The doses are obtained by multiplying the neutron flux by the dose conversion factor for the particular region and energy group under consideration.

END